USING THE MOBILE DATA COMMUNICATIONS TERMINAL AN/TYC-5 AS AN AUTODIN TERMINAL

Bruce David Thoreson

NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

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Bruce David Thoreson

Thesis Advisor: P. E. Cooper

March 1974

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Bruce David Thoreson
Major, United States Marine Corps
B.S., University of Wisconsin, 1961

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
March 1974

ABSTRACT

This thesis examines the use of the TYC-5 as an AUTODIN terminal, working from a remote location into AUTODIN. Emphasis is placed on examining the various transmission mediums used to support the TYC-5. Included are cable, micro-wave, tropospheric scatter, high frequency radio and satellite. Required accessories; operational experiences; expected reliabilities and efficiencies; and operational parameters/constraints are examined for each medium. The shortfalls that exist today in providing each of the mediums are identified. The responsibilities for providing support to eliminate these shortfalls are also identified. The conclusions show the preferred TYC-5/transmission medium combination to be with cable/micro-wave. The most critical shortfalls are also identified. The twelve recommendations are actions that should be taken to reduce shortfalls and provide for better high data rate communications from a remote area.

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I. INTRODUCTION

A. HISTORY OF THE AN/TYC-5

The TYC-5 idea was conceived in the spring of 1968. The Marine Corps recognized a requirement for a tactical Mode I AUTODIN terminal which could be housed within a S280 type shelter and could be transported by a military two and one-half ton truck, aircraft such as the C-130, or in ships such as the LST. In addition to punched cards and punched paper tapes the Marines wanted a terminal with high speed printers which could monitor all of the receive traffic as well as provide a record of all transmitted messages. The Marines also wanted a terminal which could provide all the necessary functions and features that they required without resorting to a stored program computer. No one had offered such systems until Control Data proposed using a militarized version of a CDC commercial product known as the 1717-1 Data Set Controller. This particular piece of commercial equipment had been developed, tested and certified by DCA in the spring of 1968 and is a hardware peripheral designed especially for the Control Data 1700 computer line. By removing the computer interface and adding a peripheral I/0 interface the modified 1717-1 became an ideal system controller for the TYC-5. In May 1968, a scale model of a proposed S280 configuration and an unsolicited proposal were submitted to HQMC. The model and proposal were evaluated and on 1 October 68, a sole

source contract was let to design, fabricate and test three identical models of a Data Communications Terminal which was to become the AN/TYC-5.

The Control Data Government Systems Division, now the Aerospace Division, in Minneapolis did an outstanding job in building and testing three complete systems in a 10 month period. After training four engineers and assembling a logistics support package, the TYC-5s were dispatched to operating locations. One was delivered to Da Nang, Viet Nam and was placed in operation in January 1970. A second was delivered to Okinawa and went into service during 1970. The third was delivered to the Marine Corps Communication-Electronics School at San Diego, Ca.

The Marines stated purpose in proceeding with their sole source award was to obtain sufficient samples for test and evaluation in order that they might implement a "try before you buy" program with limited funding. During the course of several years of operation, TYC-5 systems were used as though they were production hardware. In some field locations as many as 20,000 messages were sent and received each month while data on reliability and maintainability was being documented by Control Data field engineers assigned to each of the three test and evaluation systems.

In 1971, the Marine Corps seemed to be well satisfied with the operation and reliability of the TYC-5s. Using the evaluation capabilities of the Marine Corps Development Center at Quantico, Va.,

data was gathered reflecting improvements recommended for incorporation in production models of the TYC-5. After the recommendations were gathered and studied, the items selected for incorporation in the production units amounted to approximately two dozen minor items, all of which could be considered feature improvements. Functionally the test models and production models are equivalent.

Being satisfied that the TYC-5 was a very capable AUTODIN terminal, the Marine Corps began to look at applications in which the TYC-5 could be used as a high speed data terminal with transmission facilities provided by organic Marine Corps equipments.

Recognizing that the TYC-5 had the makings of a very capable data terminal the Marine Corps sponsored a development to incorporate magnetic tape subsystems which would permit simultaneous transmission and reception of 9600 bits per second. The magnetic tape system uses industry standard half inch, 800 bits per inch, nine track tape.

On 30 January 73, the Marine Corps awarded Control Data a sole source contract for 19 improved versions of a TYC-5. In addition, the Marine Corps also placed orders for the complete logistic support of the TYC-5s. As a result, Control Data will deliver the first two models of the new version of the TYC-5A in June 1974. One version will be shelterized and the other version will be without a shelter and will ultimately be installed in the Marine Corps Communication-Electronics School at 29 Palms, Ca. Production models of the TYC-5A will be fully tested and certified MILSPEC systems.

B. INTENDED USAGE

The basic intent of the TYC-5 was to be able to handle high speed data transmission for USMC units. The capability to interact with the AUTODIN network as an AUTODIN Mode I terminal and therefore pass high speed data over AUTODIN was a prime consideration. However, it was also desired that the TYC-5 could be employed in a point-to-point configuration for the passing of high speed data. Some of the data requirements growing out of the Marine Tactical Data System (MTDS) were thought to require some means of transmission that perhaps the TYC-5 could fill. It was intended that the TYC-5 could fill both of these applications without extensive modification.

The TYC-5 was not a singular consideration however, it was envisioned as one of three major components comprising a complete communication center. One of the other components, the AN/TGC-37, was a teletype, torn-tape relay van that could act as an interface between the TYC-5 and subordinate units. The TGC-37 would support six half-duplex, 60wpm teletype circuits to subordinate units, to include torn-tape switching between them, and provide a 100wpm full-duplex channel to the TYC-5 site for entrance into AUTODIN. The third component in the complex was designated as the AN/MGC-(   ) but was never developed beyond basic definitions. This was to be the mobile/transportable message center. It would provide for message preparation facilities, message filing capability, a message distribution system and the administrative space to control the complete communication center.

C. NON-AUTODIN USAGE

There are some unique data exchange requirements within USMC units. The Tactical Air Operations Center that would be linked by MTDS may well have additional data to exchange with other commands within the objective area. This would be a possible use of the TYC-5. Additionally, dedicated ties between large active supply facilities could generate sufficient data to require point-to-point high speed data terminals such as the TYC-5. Further requirements for high speed data transmission arise as the concepts for distributed data base systems and distributed processing systems are further developed by the data processing community.

For example, the Manpower Management System (MMS) and the Joint Unified Military Pay System (JUMPS) used by the Marine Corps operate on a master data base in Kansas City, Mo. This data base contains all personnel and pay records and centralized personnel processing and pay is generated there. The input for this system is from all Marine activities. To facilitate this in a garrison or semi-garrison environment, certain large Marine Corps installations are designated as MMS/JUMPS satellites. These installations receive personnel and pay record transactions from their assigned surrounding area via narrative means, run a local process on the information and then transmit via AUTODIN all of the transactions to Kansas City. Kansas City updates the master files and changes pay and personnel records accordingly.

For combat or deployed units, this same information is required for their proper administration. It is very much time sensitive since survivors benefits and combat strength totals are items that are readily available from this data. Viet Nam was the first conflict during which these systems were in effect. Even then only part of the system was implemented. To provide the computer support for the large number of personnel in Viet Nam, it was necessary to establish a MMS/JUMPS satellite in Viet Nam. This allowed the local pre-processing and reduction of information that had to be transmitted via AUTODIN to Kansas City. Although the computer also handled the supply management at the Force Logistics Center, all of these functions could have been performed just as well by a computer in a secure location given adequate communications to provide for remote job entry into the computer. This concept would reduce the number of large general purpose computers required and preclude the moving of them into hostile environments. The remote job entry capability would still provide the on-site user the computer support he requires. Concepts that call for remote job entry devices to support high volume users entry into a very large centralized computer, should consider the capabilities of the TYC-5. This terminal could possibly meet the high speed multi-media requirements that would be normal for a remote job entry terminal. The possibilities of standardization of high speed data terminal equipment, used in this manner, would be most worthwhile to examine.

II. AN/TYC-5 AND AUTODIN

A. DESIGNED INTERWORKINGS

AUTODIN has specific requirements on terminals that may be interconnected with the network. Similar, at least to the voiced policy of Bell Telephone that the wrong type of "foreign attachments" may degrade the quality of the network, definite interface standards must be met. These standards are set by DCA in accordance with their charter to maintain the integrity of the DCS. To ensure the compliance of these standards, certification must be accomplished before a terminal is allowed to enter the network. The TYC-5, although a tactical, mobile device, was subjected to this certification testing. The TYC-5 in its design configuration meets all of the DCA phases of certification. Phase one is primarily a testing of the actual machine configuration to ensure the "nuts and bolts" type standards are being met by the device. Such things as out-put levels, code structure, out-put wave forms, etc., are looked at during this test phase. Phase two is intensive TEMPEST testing. This is basically security testing for spurious emanations. The final test, phase three, consists of an actual operational test while connected to an AUTODIN switch. Specified test messages are passed and efficiencies and reliabilities are computed.

B. NECESSARY AUTODIN FUNCTIONS

The AUTODIN network has a relatively busy operating system controlling it. All of the synchronous terminals are very much under its control. These terminals are continually interacting with the AUTODIN Automatic Switching Center (ASC) indicating availability or non-availability. When message traffic is introduced from either the switch or a terminal, a handshaking procedure is involved. Two modes of operation are used. The block-by-block transmission mode is the easiest to understand. In this case a check is made for line availability, then a machine preamble is sent for synchronization. After this is accomplished, each block, i.e., 672 bits, is transmitted, and either an acknowledgement (ACK) or non-acknowledgement (NACK) of receipt is received by the sending station. If ACK, then the next block is transmitted, if NACK, then the same block is retransmitted. After three attempts to transmit the same block, a system alarm occurs and operation ceases pending operator intervention. To the system, the distant end is considered down.

The continuous mode is a little more complicated than the block-by-block mode but it has certain performance advantages. Two blocks are initially transmitted and acknowledges accepted for each at a certain time later. If the acknowledgement for the first block (ACK1) is received before the second block has been completely transmitted then the way is clear to transmit the third block while waiting for the second block's acknowledgement (ACK2) and so on alternating ACK1 and ACK2.

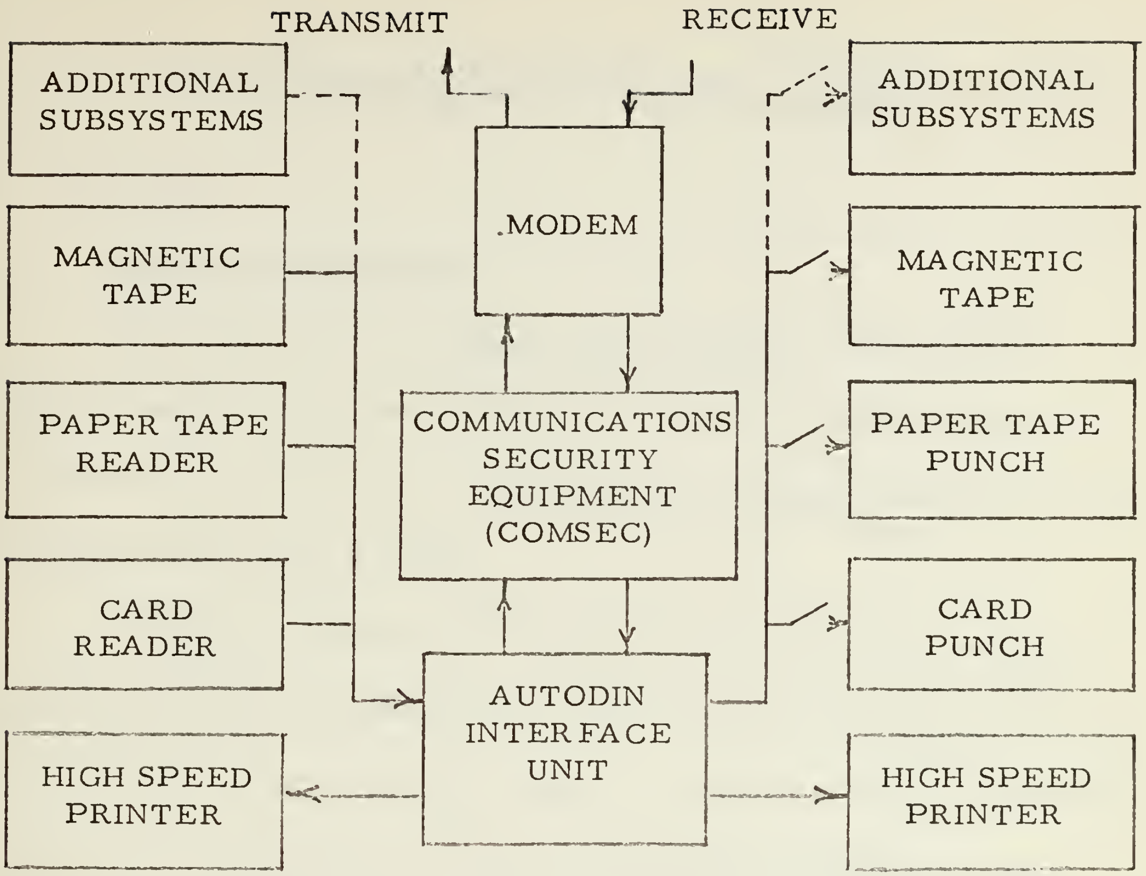
If a block is not acknowledged (NACK) then both the erroneous block and the block in progress of being transmitted are retransmitted. In this way block sequencing is kept correct although the second block is transmitted twice. Again after three attempts to send the same block fail, the system considers the distant end down.

The response time for the ACK or NACK is insignificant on all transmission media except satellite. In the cases where it is insignificant, traffic throughout will be expected to increase by only 4-5% in the continuous mode over the block-by-block mode. On a properly operating satellite link however, significant increases of traffic throughput can be expected in the continuous mode.

Additionally coordinated switch and terminal sequential channel numbering systems exist. This is to ensure no lost messages. If the channel number on the message being sent, which is automatically entered by the switch or terminal, is not the expected number at the other end, an error condition exists and the system must alarm. These conditions are typical of the interaction required between synchronous AUTODIN terminals and the ASCs. All of these interactions are included in the TYC-5 and make it totally compatible with AUTODIN. When two TYC-5s are used in a point-to-point configuration, each looks like an ASC to the other and the normal handshaking procedure goes on.

C. SPEEDS AND MEDIA AVAILABLE

The TYC-5 is a most flexible terminal. When used as an AUTODIN terminal the TYC-5 can operate at 75, 150, 300, 600, 1200 and 2400 baud either in a continuous or block-by-block mode. When used in a strictly terminal-to-terminal configuration and utilizing the magnetic tape medium, speeds of up to 9600 baud are possible. The TYC-5 is equipped to handle a variety of message media. Originally designed for only paper tape and punched card input and output, a recent contract has developed and is now producing a magnetic tape subsystem that can be used as an add-on package when required. All of this of course is in addition to a page printer for hard copy of messages. Figure 1 shows these various configuration capabilities.



PAPER TAPE READER
- 300 Characters/Sec.
- 5, 7 and 8 Level
- Chad and Chadless
- Read after Read
- ITA #2 or ASCII

PAPER TAPE PUNCH
- 240 Characters/Sec.
- 5, 7 and 8 Level
- ITA #2 or ASCII

CARD READER
- 300 Cards/Min.
- Read after Read

CARD PUNCH
- 250 Cards/Min.
- Read after Punch

MODEM
- MD-701 A/UY

HIGH SPEED PRINTER
- 1100 Lines/Min.
- 64 Printable Characters
- Sprocket and Friction Feed

MAGNETIC TAPE
- 800 Bits/In
- 37.5 Inches/Sec.
- NASI STD., X3.22 Compatible
- Variable and Fixed Length Alphanumeric Records

AUTODIN INTERFACE UNIT
- DCA Certified
- Militarized Construction
- Small Size and Weight (16 in. panel/95 lbs.)
- Hardwired
- Operates Up to 40.8 Kilobits
- Expandable I/0 Interface

FIGURE 1

III. LINKING THE AN/TYC-5 TO AUTODIN

A. BY CABLE

1. Required Accessories

The AN/TYC-5 is equipped with a MD-701 A/UY modem. This is a standard wireline modem and therefore no additional accessories are required for the TYC-5 to be used in conjunction with a cable or landline transmission media.

At this point, however, it is worthwhile to discuss required support for the TYC-5 regardless of transmission media being employed. The TYC-5 has no organic power supply. It requires 18kVA 120v/208v, 3 phase, 4 wire 60Hz power. Since cryptographic devices are an inherent part of the TYC-5, the power source must be relatively stable to allow maintenance of the cryptographic synchronization.

There is another area of major support required. The TYC-5 is strictly a terminal capable of transmitting and receiving record message traffic at very high data rates. The TYC-5 does not possess any significant message processing capabilities. Chapter I outlined the initial concept of the TYC-5 that would have provided the necessary message processing facilities to support a high speed terminal. Since this has not been accomplished, some type of message processing support must be provided. In the case of normal teletype traffic sufficient teletype machine positions must be available to act as a tape factory

for the TYC-5. These machines would vary in number depending on the traffic load anticipated at a particular unit. A means of reproducing the incoming teletype message traffic would also have to be provided.

In organizations where data pattern traffic is passed, a large amount of message preparation responsibility is placed on the data processing user. In the case of punched card traffic, the "deck" of information cards is prepared by the data user. The communications center prepares only header and trailer cards that are necessary for the message transmission. Therefore in this environment a couple of card punch machines are required. Additionally a card counter and card interpreters are required to process incoming and outgoing punched card traffic.

Magnetic tape traffic is totally prepared by the user and only a minimal amount of accounting is required by the communications center. The requirement for record keeping and the time consuming problem of handling incoming and outgoing narrative message traffic are probably the largest areas of support required to make the TYC-5 a feasible terminal for a given situation. These requirements are independent of the transmission media used. See APPENDIX A for a more detailed proposal for supporting the TYC-5.

2. Experiences

For a new item of equipment being introduced into the inventory, the Marines have quite extensive experience with the TYC-5. As mentioned earlier two of the initial three TYC-5s were placed into service.

The first system was delivered to the 1st Marine Division in Da Nang, Viet Nam. There it provided the AUTODIN entrance for that Division. The other major Marine units in the Da Nang vicinity were utilizing leased IBM-360/20 or UNIVAC 1004 AUTODIN terminals for the same type of support. Since the communications center at the 1st Division was operating prior to the arrival of the TYC-5, the TYC-5 was more a consolidation of existing facilities. An addition was constructed on the existing communication center (itself being a series of quonset huts) and the TYC-5 was basically brought inside. The action went a long way to alleviate the problems of torn, dirty paper tapes or wet, swollen punched cards if either is carried in and out of a number of buildings or facilities. Prior to the installation of the TYC-5, the 1st Division had 100wpm full-duplex, teletype circuits to the 1st Marine Air Wing, the Force Logistics Command, the Third Marine Amphibious Force and two to the Defense Communications System (i.e., AUTODIN). Although all existing circuitry to the other Marine units was not removed, since all were served by AUTODIN, the traffic normally passed over these five circuits was subsequently passed over the TYC-5 into AUTODIN. The TYC-5 was linked to the DCS backbone system in Viet Nam by telephone cable installed by the U.S. military. Total cable length was approximately seven miles of which part was aerial and part buried. Major portions of the cable runs varied from 50 pair to 300 pair cables with numerous cross-connect points. The configuration and maintenance of this cable run was definitely below normal Bell Telephone

standards. As a result, a number of outages were directly attributed to this cable. However total operation was not unacceptably interrupted. The terminal was in operation for over a year.

System number two was delivered to Marine units on Okinawa. It became the AUTODIN terminal for the 3rd Marine Division and Camp S. D. Butler. The 3rd Division located at Camp Courtney was approximately twelve miles from the AUTODIN switch at Fort Buchner. This was over cable that had been installed over the years and maintained by various U. S. government agencies. Circuit standards again did not meet Bell specifications but proved adequate to handle the 1200 baud operation of the TYC-5. The TYC-5 at Camp Courtney acted as an interim terminal. The 3rd Division had recently returned from Viet Nam and the two 100wpm teletype circuits at Courtney were inadequate to support the increased message load. A Digital Subscribers Terminal Equipment (DSTE), which is a government owned high speed Mode I AUTODIN terminal, was scheduled for installation at Courtney. The necessary site preparation and the simultaneous uprgrading of the existing communication spaces at Courtney prevented an expeditious installation of the DSTE. The existing communication center was on the second story of the Headquarters building. The TYC-5 was parked adjacent to this building and connected into AUTODIN. Even with this extreme inconvenience of message processing being done on the second story and all messages being run back and forth to the TYC-5, the

message throughput was more than adequate to support the command. This system was in operation approximately a year.

During the last five months of 1970, the two terminals processed approximately 142,000 messages. These two operations have played an important role in determining the suitability of the TYC-5 as a tactical data terminal for use with AUTODIN.

3. Reliability

In both locations for the TYC-5, the downtime of terminal equipment itself was the minor portion of system outages. In both cases there are conflicting circumstances surrounding this low amount of outages. First, these are systems with no previous maintenance records, therefore the parts support was based on engineer and designer estimates. Secondly, a factory field engineer was in attendance at all times. Whereas the first circumstance may well cause extended outages, the second will reduce that possibility to the utmost. The low outages speak well of equipment design and production.

4. Efficiency

In this paper throughput efficiency is given by the ratio of the time needed to transmit the same block of data through a perfect, error free channel over the time needed to transmit the same block of data over a real channel with errors including the time used in channel control, the time needed to send retransmissions and any time wasted waiting for acknowledges to blocks as well as retransmissions:

$$\text{THROUGHPUT EFFICIENCY} = E = \frac{T_{BL}}{T_{BL}+N_R T_{BL}+T_W+T_{cc}}$$

where: T_{BL} = One block time

N_R = Number of retransmitted blocks (on the average)

T_W = Time wasted, if any, waiting for acknowledges

T_{cc} = Time used in channel control such as acknowledges in reverse direction and any extra added to the blocks

With the AUTODIN system design attempting to keep T_W and T_{cc} at a very small value, the retransmissions $N_R T_{BL}$ are the main contributing factors to lowering efficiency. Basically the throughput efficiency is the ratio of new information being received over the total amount of information being sent (including retransmissions). [Ref. 1]

Unfortunately these logical and valuable efficiencies are not readily available in the normal operating AUTODIN system. The AUTODIN defines efficiency as percentage of time a terminal is available for passing traffic as compared to the total time in a given period. This definition, although of value when comparing systems for availability, does not measure the operational throughput efficiency.

The efficiency, as defined by AUTODIN, for the two systems discussed is shown in Table 1.

5. Operational Parameters/Constraints

Minimal constraints exist when operating the TYC-5 over cable into an AUTODIN switch. Minimum care must be taken in the

circuit routing for this configuration. Excessive cross-connects should be avoided. When operating at 1200 baud or less, the standard (Bell) voice grade circuit is adequate for operation. At data rates much greater than 1200 baud, circuit conditioning equipment may be required.

Table 1

Date 1970	Terminal	Messages Sent	Recd	Total	Outages (hr) Ckt	Crypto	Term	Other	% Eff
Aug	Viet Nam	10929	4645	15574	1.67	.52	.74	.25	96.82
	Okinawa	11994	4943	16937	.49	3.93	.68	.51	94.39
Sep	Viet Nam	3205	1323	4528	1.34	.62	.00	3.57	94.47
	Okinawa	12161	5015	17176	.49	2.38	.40	.00	96.73
Oct	Viet Nam	10269	3834	14103	3.46	.82	.57	.14	95.01
	Okinawa	12350	5109	17459	.16	.39	1.06	.00	98.39
Nov	Viet Nam	8962	3341	12303	.66	.20	.03	.67	98.44
	Okinawa	10315	4395	14710	1.27	1.18	.54	.05	96.96
Dec	Viet Nam	9346	3763	13109	1.28	1.59	.17	.36	96.60
	Okinawa	11285	4736	16021	.16	.33	.04	.11	98.56

B. BY MICRO-WAVE

1. Required Accessories

Since the micro-wave is basically a RF carrier for cable systems, the standard wireline modem in the TYC-5, the MD-701 A/UY, is adequate for micro-wave applications. No other particular accessories are normally required for utilizing the TYC-5 with micro-wave. The word normally is necessarily inserted since a fairly stable micro-wave channel is required and a prerequisite of such a channel is "absolute" line-of-sight between the micro-wave antennas. In the one

operational experience the Marines had using the TYC-5 over a micro-wave link, the high surrounding vegetation was too tall an obstacle for the standard AN/TRC-97 masts. As a result a standard U. S. Army Signal Corps tower, the AB-216, was utilized to allow placing the TRC-97 antennae at 70 feet (transmit) and 50 feet (receive). Since these conditions may not be that unique, some type of tower may become a required, or at least desired, accessory when using the TYC-5 over a micro-wave link.

2. Experiences

The operational experience of the TYC-5 over a micro-wave link started in May 1972. It was in late May 1972 that units of the 1st Marine Air Wing deployed from Iwakuni, Japan to what was basically a bare base at Nam Phong, Thailand. Communications requirements to support this deployed unit included high speed, multi-media AUTODIN access. The multi-media aspects were required due to imposed reporting requirements for 3M, MMS, MARES and some supply oriented transactions, all of which are punched card oriented. The initial planning included a low powered tropospheric scatter (TROPO) link from Nam Phong to Khon Kaen some 17 miles away. This link was only marginally satisfactory due to the poor scatter effect at that distance and the tree covered intervening terrain. The circuit quality in the TROPO mode would not support a high speed data link required for the TYC-5. The 15 foot masts, organic to the TRC-97 (micro-wave/TROPO)

did not permit raising the antennas above the tall trees surrounding the Nam Phong area. An attempt was made to establish a TROPO link to Udorn which was 53 miles away. This was unsuccessful because site selection restrictions at Udorn precluded avoiding a large hill mass, 13 miles from Nam Phong, and some 700 feet higher than either Udorn or Nam Phong. During July 1972, U. S. Army Signal Corps elements in Thailand provided a standard Signal Corps tower, AB-216, (FSN 5450-542-456) to the Marines. This tower was modified in the field from 75 feet to 126 feet high. The TRC-97 antennas were placed at the 70 foot level for transmitting and 50 foot level for receiving. The mode of operation for the TRC-97 was then changed to line-of-sight (LOS). Immediately, circuit quality improved dramatically. The RF link performed almost flawlessly from that point on.

During these different attempts to lock in a solid circuit path over the TRC-97s, it was noted that very frequent adjustments of line amplifiers in the TRC-97s at each end of the link were required, first increasing gain, then decreasing gain. It became apparent that Nam Phong was adjusting to a signal that was fluctuating wildly, which was not at all to be expected from a DCA engineered circuit. The TRC-97 was designed to accept a signal of OdBm to -10dBm with signaling 19dB below that in accordance with MILSTD 188. Measurement of the signal strength being furnished to the TRC-97 at Khon Kaen from the minor technical control there, determined that the signal was a -16dBm with

signaling 19dB below that. The TRC-97 at Nam Phong was being given a signal that it could not compensate for. DCA Thailand was requested to examine the circuit engineering and provide a signal in the OdBM to -10dBm range. DCA Thailand reconfigured the equipment at Khon Kaen and then Nam Phong received a -4dBm signal, well within its capabilities to compensate for fluctuations. The circuit became a high quality circuit with a fade margin of 65dB. The TYC-5 at 1200 baud operated very reliably over the link even during heavy monsoon rains and thunder storms. The main remaining problems were the TRC-97s organic generators. Once these were replaced by larger garrison-type generators (MUSE), the TYC-5 circuit rose from an average of 75% efficiency in August 1972 to above 98% and maintained that level.

The incoming narrative message traffic on the TYC-5 started at 130 messages a day and rose steadily to over 500 messages a day by the end of the month (July 72). The 500 incoming narrative messages each day was a fairly normal occurrence throughout the remainder of the deployment.

Card traffic did not commence until 11 July 72. The delay was partly caused by moisture laden cards which the high speed card reader could not accept. This condition was caused by the lack of air conditioned work and storage spaces. [Ref. 2]

3. Expected Reliability

The reliability of the system started out so poorly while in the TROPO mode, that the expected reliability of the micro-wave or LOS

was not near the 95-98% reliability that eventually evolved. The reliability seemed most dependent on the equipment's power sources once the signal levels had been adjusted and the LOS mode of operation assumed. With the exception of a 1208 minute demand maintenance outage for the terminal equipment (TYC-5) in June 73, which was greater than the total equipment outage times for March through August (excluding June), the terminal equipments accounted for only 29.1% of the total outages for that six month period. Circuit outages accounted for 34.2% and crypto, power, air conditioning and other accounted for the remaining outages.

4. Expected Efficiency

During these six months, using DCA's definition of percent efficiency to measure the system availability, we find this figure never dropped below 96.32%. Table 2 shows traffic, outages and efficiencies for these months as compiled by DCA.

Table 2

Date	Messages			Outages (min)				%
1973	Sent	Recd	Total	Ckt	Crypto	Term	Other	Eff
Mar	10678	3464	14142	46	60	163	461	98.36
Apr	11171	3286	14457	235	31	715	41	97.63
May	11075	3512	14587	145	70	472	-	98.46
Jun	11283	3653	14936	179	144	1208	55	96.32
Jul	10783	3832	14615	-	309	92	56	98.98
Aug	9980	3934	13914	372	119	72	17	98.70

5. Operational Parameters/Constraints

The obvious constraint when operating over a micro-wave link, is to be able to provide absolute line-of-sight between the antennas. Vegetation, foliage or a hilltop can easily provide sufficient interference to preclude dependable high speed data transmission. As compared to a system operating over a cable or landline, much greater power requirements exist and therefore the amount of power and air conditioning required becomes more critical.

C. BY SATELLITE

1. Required Accessories

Within very nominal constraints no particular accessories are required when using the TYC-5 over a satellite link. Two conditions must, however, be met. Due to the full-duplex mode of operation, a four-wire wire line access must be made to the satellite terminal. This would be a typical connection for a 3kHz voice frequency channel. Since this is an expected configuration, most satellite terminals of today or the future should be compatible, for interconnects. The one other condition that must be met is a compensation for the extended circuit path if any relatively high speed, in excess of 600 baud, transmission is expected. This problem will be addressed in more detail later.

2. Experiences

Little experience is available with the TYC-5 and satellite transmissions. One brief test was conducted on 24-26 May 70 by the

9th Communications Battalion at Marine Corps Base, 29 Palms, Ca. This test was to demonstrate the capability of utilizing the then current Marine Corps Tactical Satellite Equipment AN/TSC-80 and the Tactical Data Communication Terminal TYC-5 for 1200 baud continuous data transmission from data terminal to data terminal over TACSAT-1.

3. Time Distance Problems

Before the actual testing could get underway, some very special considerations had to be made. For the first time in data transmission, utilizing the AUTODIN handshaking procedure, the length of the circuit path had become a significant factor. With TACSAT-1 being located 22,000 statute miles above the equator at approximately 180° W longitude and 29 Palms Ca. (the test site) being located 35° N latitude, 116° W longitude, the slant distance to TACSAT-1 was computed as 25,092 statute miles. Since the test was utilizing the TYC-5 in a back to back mode, the up-link and down-link distances were the same for a total link length of 50,184 statute miles. In computing signal delay over this path both the TYC-5 and TSC-80 were assumed to contribute a negligible delay to the path. Additionally no delay was attributed to the atmosphere. Rather a straight forward computation using the circuit path length and the speed of light in a vacuum was used. The resultant delay was 269.5 milliseconds. Since an acknowledgement is required prior to transmission of the second block in a block-by-block mode of operation (or prior to the end of the second block in a continuous mode) double the delay time

must be considered. Therefore after the end of block one, 539ms expire before the beginning of block two, all attributed to delay caused by the length of the circuit path. It was interesting to note that in the test a theoretical maximum delay was calculated. This was based on the worst location that could adequately access the TACSAT-1 satellite. The primary restriction was a minimum of a 6^{o} elevation angle. Within this constraint the maximum round trip delay would be 549ms. This would indicate that the test was being conducted at very near the extreme condition.

To adjust for this delay and therefore enable high speed transmission, the contractor developed an adjustable delay module in the AUTODIN interface unit of the TYC-5. This turned out to be a relatively simply plug-in card module that allowed transmission of the next few line blocks while awaiting ACK for the first. Basically it was a step further down the road than the continuous mode and usually was allowing about seven line blocks to be transmitted prior to receiving ACK for the first. If the first was in error, i.e., NACK received, it and the subsequent six line blocks would be retransmitted. This was a simple to install modification that can easily be carried as an insertable component.

The test results proved conclusively that the use of the Tactical Satellite Communications Terminal to provide the transmission path for high speed message transmission from TYC-5 to TYC-5 is operationally feasible. [Ref. 3]

4. Efficiency

Data was successfully passed, apparently with few or no retransmissions. Throughput rates were measured and found to agree very closely to those predicted for a low error rate satellite link. Test results and predicted results are shown in Table 3.

Table 3

Information Rate	AUTODIN Mode	Throughput blocks/min	Measured Eff	Predicted Eff
1200bps	continuous	102	.98	.99
1200bps	block-by-block	53	.51	.50
2400bps	continuous	105	.50	.52
2400bps	block-by-block	75	.36	.35

Also note that even though the data rate was doubled to 2400bps in part of the test, the throughput as shown in Table 3 remained essentially the same. This was due to the round trip delay time being significant compared to the transmission time of one block. This result demonstrates the futility of trying to increase the throughput on a satellite link by merely increasing the data rate to 2400bps under the existing AUTODIN rule. However, if a maximized throughput type system were used, the throughput could be brought up to the 214 line blocks per minute rate typical of a normal 2400bps operation. [Ref. 1]

5. Reliability

Reliability for this system is rather difficult to establish. The TYC-5 itself has very high reliability factors. On each occasion

that the TYC-5 has been used for an extended period in an operational role, the transmission media has been the controlling factor in reliability. With no specific tactical satellite terminals being identified for the near future, no reliability factors can be assigned to them, however, present technology should provide reliability to the degree required. Perhaps the more difficult question to address is the satellite portion of the link. Although the TACSAT-1 and LES-6 survived long beyond their predicted lives, periods of sporadic behavior occurred. Launches of the first satellites to support the DCS satellite system were failures. At this time there is no global coverage of military communication satellites. Therefore reliability must be zero. Projecting somewhat into the future, the Navy Fleet Satellite program should provide tactical satellite coverage to most parts of the world. That satellite system has good predicted reliability. Combining the TYC-5, a good satellite terminal and Fleet Satellite reliabilities, this method of transmitting data in the future should be the most reliable.

Two areas of caution are necessary. The Fleet Satellite program envisions a series of geostationary satellites. Due to this positioning no coverage will be made at the northernmost or southernmost latitudes. A terminal located in either of those areas may find marginal or absolutely no reliability with the system. The other area of reliability lies in the philosophy of satellite maintenance. If a

catastrophic failure occurs, or if by some technique a foreign government disables one of the satellites, the philosophy of satellite replacement is critical in determining reliability. Either prepositioned spares in space, relocating existing satellites or ready to launch vehicles could be used to meet these requirements. Only after computing these alternative times to replace a satellite can you address the reliability of the system over an extended period of time. All of the alternatives are probably measured better in days vice hours in restoration of the service.

6. Operational Parameters/Constraints

On the surface few parameters or constraints appear in satellite operations. If functions and connections on any satellite terminal are similar to the TSC-80, no inter-connect problems are anticipated. Minor considerations of siting are required to ensure a clear view of the satellite by the terminal. Additionally, an elevation angle of less than 6° should be avoided.

Perhaps the largest single constraint is the distant termination. As was earlier discussed, the extended circuit length brings excessive delay times into the system using the AUTODIN handshaking method of operation. As a result a modification or delay must be inserted in the system to allow high speed data transmission. Additionally an attempt to increase throughput by simply increasing terminal speeds becomes fruitless at much over 1200bps while remaining within existing AUTODIN rules.

Although the Defense Communications Agency System Engineering Facility (DCASEF) has been made aware of these problems or limitations, no changes have been made to the AUTODIN operating system to accommodate those AUTODIN subscribers desiring to access the ASC at high data rates via satellite. Although studies conducted with Western Union, the prime contractor for AUTODIN, indicate only minor software changes would be necessary to accommodate the delay problem, this approach is not being followed. AUTODIN is facing an onslaught of high speed data traffic. The proposed software patch would only address one small segment. Supposedly for this reason, efforts in other areas are being made. The present effort appears to be a new system of packet switching. This appears to be modeled after the Advanced Research Projects Agency (ARPA) network which works extensively in this manner. A description of the ARPA network and its general functioning can be found in APPENDIX B.

The examination by DCASEF is in too early stages to offer a particular technique or utilization of packet switching techniques to support satellite equipped AUTODIN terminals. This author would envision the following technique:

Given that the existing AUTODIN network is reconfigured to resemble the ARPA network, each ASC would be equipped with one or more interface message processors (IMPS) to break the data stream into packets of 1000 bits or less and communicate with

adjacent IMPS (at other ASCs) to transfer each packet over 50 kilobit or greater transmission lines. If each ASC were equipped with two additional IMPS, each feeding into a satellite terminal that would be looking at different satellites, packets received over the satellite links could interface with the ASC. The satellite links would of course need to be reconfigured. For each satellite terminal supporting an AUTODIN terminal, two circuits back through the satellite to the IMP at the ASC would be required. One would be a wideband path, perhaps 50 kilobits, for the transmission of data. The wide bandwidth would allow for very high data rates. These data rates may be sufficiently high to require only half-duplex operation and therefore require only the one 50 kilobit channel at each terminal. The other channel required could be a nominal 3kHz voice channel and simply be the orderwire for the IMPS to determine if the distant IMP is busy. The IMP at the ASC would require some type of combiner to accommodate the low speed orderwires from the outlying terminals. For this reason primarily the IMP at the ASC may need to be slightly larger and more complex to be able to interact with a number of distant terminals and allot the one 50 kilobit channel on a timely basis. Basically the transmissions over the 50 kilobit channel would be in packet form. To allow for the maximum utilization of the 50 kilobit channel, packet sizes of 10K or 100K bits would be utilized. This would allow most messages to be included in one packet. The ACK

or NACK time of the IMP would become insignificant compared to the transmission time of a 100K bit packet. The IMP at the terminal would need sufficient storage to buffer the terminal input and build, using filler when required, the 10K or 100K bit packets. Basically it would be a burst transmission type technique. Otherwise the IMPS would act in the same manner as those in the ARPA network to include acknowledgement of receipt by packet and packet control to ensure proper message reconstruction at the ASC for processing. Figure 2 shows a block diagram of the proposed configuration.

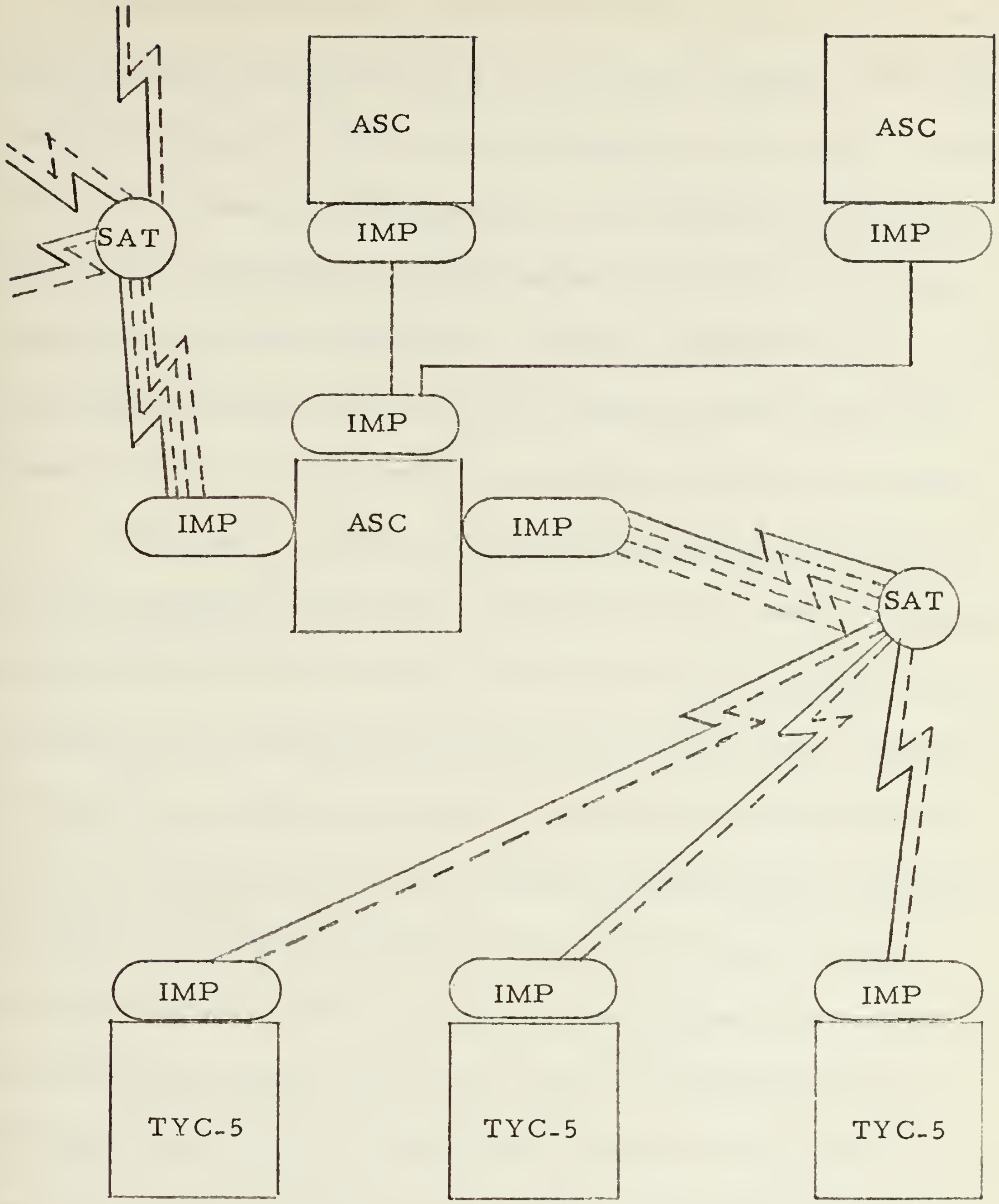
D. BY TROPOSPHERIC SCATTER

1. Required Accessories

In addition to the TROPO link itself, an accessory that may be required when operating high speed data over a TROPO link is some type of error detection and correction (EDAC) device. Next to high frequency (HF) radio, TROPO links have the most varience in circuit stability and some gains can sometimes be made with EDAC.

2. Experiences

No long term operational experiences have occurred transmitting high speed data over TROPO. However a series of tests have been conducted by the Naval Electronics Laboratory Center (NELC) and the U. S. Marine Corps to look at the feasibility of utilizing TROPO to tie the TYC-5 into AUTODIN. These tests were conducted over a period of time from March 1972 to January 1974. These tests pointed out areas that may require continued testing.



50 Kilobit Landline
50 Kilobit Satellite Channel
3 kHz Satellite Voice Channel

IMP	Interface Message Processor
ASC	Automatic Switching Center
SAT	Satellite
TYC-5	Tactical Data Communications Terminal

FIGURE 2

In the earliest test, the week of 13 March 72, a TYC-5 was used to transfer AUTODIN data over a 90 mile overwater TROPO link from Point Loma, San Diego to Fort MacArthur, San Pedro, Ca. and back to Point Loma. The radios used were USMC AN/TRC-97E 12 channel FDM tropospheric scatter radios utilizing 8 foot diameter transmit and receive antennas at a 1000 watt average RF power level. Dual space diversity combining in the radio was used for all tests. A single TYC-5 was operated in a loop back condition over the link.

Propagation conditions were abnormal the first two days of the week resulting in no contact. On the third day conditions changed so much that the link was able to sustain AUTODIN type data transfer with less than 1% required retransmissions due to errors. However, evening fading conditions (probably correlateable to fogbank atmospherics) were noticed each day resulting in a much lower throughput. Three tests were made at 1200bps during mild fading conditions resulting in from 12-19% required retransmissions due to errors in transmitted line blocks (block error rates). An IBM AN/USA-29 EDAC processor was used during mild to severe fading conditions, resulting in from 4-50% block error rates. Throughput rates and efficiencies are summarized in Table 4.

A separate EDAC test was made with the TYC-5 data modem ended-around to bypass the radio link. This was done to demonstrate the significant drop in throughput as more and more round trip delay

INFORMATION RATE	AUTODIN MODE	EDAC INTERLEAVING	TOTAL BLOCKS TRANSMITTED (one min. runs)	BLKS RECEIVED IN ERROR	THROUGHPUT EFFICIENCY
1200bps	block-by-block	NO EDAC	1800	21	time not taken
1200bps	continuous	NO EDAC	1000	3	time not taken
1200bps	continuous	NO EDAC	52	6	43
1200bps	continuous	NO EDAC	93	12	76
1200bps	continuous	NO EDAC	54	10	41
600bps	continuous	1	41	8	.62
600bps	continuous	5	45	2	.80
600bps	continuous	5	30	8	.41
600bps	continuous	19	15	6	.17

TABLE 4

time was encountered. The results of this test are shown in Table 5. Interleaving of more than m=89 at 1200bps information rate proved to exceed the maximum time-out timer setting (3.75 seconds) and resulted in an error condition. [Ref. 1]

A second test was conducted in late 1972. In that case a TROPO link was set up between El Centro, Ca. and Yuma, Az. a distance of 75 miles. This test didn't develop the most favorable conclusions. An NELC mobile van was equipped with high speed data modems and error counters to measure the bit error rates (BER) and the AUTODIN block error rates encountered. Both a serial 2400bps wire line modem and a parallel tone 2400bps modem were available for testing. Again the AN/USA-29 EDAC processor was employed to further access its capability for error reduction.

The system performance data given in the TRC-97 instruction manuals were used to plan the test link. At the 75 mile distance, with the sum of horizontal angles equal to zero degrees, the link was predicted to give 99% time availability with BER equal to or less than 10^{-4}. On the assumption that the bit error would be randomly distributed, the AUTODIN block error probability was predicted to be about 6%. When the link was put in operation, order wire voice communications were adequate but the BER was much higher than predicted. Several days of testing were devoted to repeated efforts to secure better antenna alignment in both azimuth and elevation.

DECREASE OF POSSIBLE THROUGHPUT WITH IBM AN/USA-29 EDAC

INFORMATION RATE	AUTODIN MODE	EDAC INTERLEAVING	TOTAL BLKS TRANSMITTED IN ONE MINUTE	THROUGHPUT EFFICIENCY
1200bps	block-by-block	1	91	.85
1200bps	continuous	1	107	1.00
1200bps	block-by-block	5	71	.66
1200bps	continuous	5	100	.94
1200bps	block-by-block	19	47	.44
1200bps	continuous	19	73	.68
1200bps	block-by-block	41	30	.28
1200bps	continuous	41	36	.34
1200bps	block-by-block	89	18	.17
1200bps	continuous	89	18	.17

TABLE 5

Many test runs were made to find optimum level settings to insure that the modulation levels were right and that the high residual error rate was not due to distortion generated in the radio equipment. BER remained high and it was concluded that the link would not perform up to the level predicted.

During this testing period a number of data samples were taken at random times. The samples contained 284 AUTODIN blocks transmitted. The results are shown in Table 6. Except for samples 8 and 9, the behavior of the circuit was typified by block error rates near 70%. This block error rate leads to transmission efficiencies of about 24% in the block-by-block AUTODIN mode and 17% in the continuous mode. In this typical high error rate situation, the EDAC processor did not provide any help in reducing block errors. Bit errors came in bursts of such density and duration that the EDAC was not able to cope. Occasionally the EDAC even lost synchronization and extended the error burst in time.

In the course of seven days when data samples were taken, the circuit improved only once for a brief period during which data samples 8 and 9 were taken. At that time AUTODIN data was passed with 70% efficiency in either mode.

From this test certain conclusions were made. At 75 mile distances over desert terrain (vice over water as in the March 72 test) the TRC-97 radios can only provide AUTODIN efficiency of about 25%

SAMPLE NUMBER	MODEM	DATE RATE BITS/SEC	AUTODIN BLOCK ERROR RATE IN %	TRANSMISSION EFFICIENCY RELATIVE TO WIRE LINE CAPACITY IN % BY BLOCK	CONTINUOUS
1	Sebit	1200	63.5	30	22
2	Sebit w/EDAC	1200	72.5	14	16
3	Sebit	1200	69.8	25	18
4	Sebit	2400	75.4	20	14
5	Sebit	1200	71.6	24	17
6	2214	1200	79.6	17	11
7	2214	2400	78.9	18	12
8	2214 w/EDAC	1200	16.3	69	70
9	2214	2400	13.6	71	71
10	Sebit	1200	74.4	21	15
11	2214	2400	38.1	51	44
12	Sebit	2400	84.1	13	9

TABLE 6

and the block-by-block mode is more efficient than the continuous mode. The failure of the test path to produce the predicted grade of service was thought to lie in the difference in basic propagation loss experienced over dry desert terrain relative to the prediction curve data given in the TRC-97 instruction book, which is typical of the Eastern United States. Apparently the dry desert atmosphere has a smaller surface refractivity which effectively adds 0.2dB path loss per N units of surface refractivity. An IEEE paper about that time determined that surface refractivity in the Western U.S. desert areas was about 45N units less than in the Eastern U.S. That would account for an additional 9dB of transmission loss which would explain the lower grade of service experienced on the test path. Charts on basic propagation losses for TROPO showed the test path would have had to be shortened from 75 miles to about 50 miles to recover the 9dB propagation loss. From this it was concluded that th TRC-97 radio sets were probably limited to 50 mile links in the desert areas and 75 mile links in Eastern U.S. type areas for supporting high throughput AUTODIN data while operating in the TROPO mode. [Ref. 4]

The latest test was conducted the week of 21 January 74. In that case the TROPO link was established from the vicinity of Barstow, Ca. to 29 Palms, Ca. some 60 miles away. NELC equipment similar to that used in the late '72 test was used. The initial TROPO installation was based on the performance data given in the TRC-97 instruction book. The link was a true TROPO shot since an intervening hill

mass exceeded either terminal location in height by over 2000 feet. The instruction book predicted a short term reliability for the link of 99.7%. Out of the week of testing, one 30.2 hour period was the only solid period of time where high-speed data was being passed. Data would pass well for a short period of time with a BER of $5.7\text{-}8.5 \times 10^{-4}$. Then the error rate would increase, once to 1.47×10^{-2}. In that particular case high winds, approximately 30 knots, were being experienced at 29 Palms, and the antennas at that site were vibrating. On other occasions when the BER would increase, some equipment malfunction or difficulty could be identified. In retrospect the actual transmission path (RF) of the test in late '72 may have not been bad and only undetected equipment malfunctions may have caused the difficulties and low reliabilities.

During the 30.2 hour period of testing, traffic was passed from Barstow through the relay at 29 Palms and back to Barstow. During this time six outages totaling 4.9 hours were identified as difficulties in synchronization or comparators, four outages totaling 1.7 hours were attributed to the relay at 29 Palms being down and seven outages totaling 1.5 hours attributed to testing equipment conditions, receiver calibration and other equipment maintenance or adjustment type operations. This left 22.1 hours of data. The block errors in this 22.1 hours of data are shown in Table 7.

Table 7

% of total data		block error rate
2.7	block error was greater than	15%
1.8	block error was greater than	2%
7.2	block error was equal to	1%
88.3	block error was less than	1%

3. Expected Reliability/Efficiency

The results of the last test restored some confidence in the instruction manuals table for installation and computing efficiencies for the TRC-97. It appeared that well maintained and properly adjusted TROPO equipment could provide a sufficiently stable link to support high speed AUTODIN type data rates at acceptable error rates.

4. Operational Parameters/Constraints

It would appear that the major constraint in passing high speed AUTODIN data over a TROPO link is the criticalness of the link itself. Terminal equipments must be in excellent condition and antennas properly installed and maintained. It would appear that the instruction manual for the TRC-97 is adequate in computing elevation angles and predicting throughput efficiencies.

E. BY HIGH FREQUENCY RADIO (HF)

1. Required Accessories

The required accessories for utilizing HF as the transmission medium to support high speed data links such as AUTODIN, can vary

considerably depending on the speed of transmission and the designated minimum error rate specified. Since HF paths are subject to many known and many unknown disturbances of varying duration, plans should be made for redundancy. Most HF radios possess combiners that allow for some types of signal diversity to provide some redundancy. The most common ones would be antenna diversity, in-band frequency diversity, out-of-band frequency diversity and polarization diversity. Each of these methods may prove to be more effective than another in a given circumstance. When a combination of these diversity methods is used, the typical combiners in the HF radios are no longer adequate. Work has been conducted at NELC to develop a majority vote logic scheme (MVL) where three or more inputs are received and, if differences exist, the majority is considered correct. The logic portion includes the ability to weight the inputs depending on conditions and therefore obtain a weighted majority. At this time of writing, work on the MVL has been confined to low speed (75 baud) applications due primarily to cost. Consider however, a TYC-5 in a remote location with only HF being available as a transmission medium. If HF frequency assignment is very limited or simply due to the geographic location and distances involved, the HF path can only support 75 baud operation, the MVL could prove to be invaluable. Utilizing as many means of diversity as feasible, the MVL could reduce the random errors and preclude the requirement for automatic

request for retransmission (ARQ) by the TYC-5. In a rather simple test between Naval Communication Station, Honolulu and the U.S.S. Constellation which was tied up at North Island, San Diego, continuous teletype traffic was passed at the rate of 424 lines (each being 69 characters) per hour for a 20 hour period. Radio receiving equipment aboard the Constellation (i.e. the VFCT) was adjusted to the dual diversity mode. In one case the component combiner of the existing radios compared the input signals, in the other case the input signals were used with the MVL. With "missed" lines being defined as lines being received with sufficient errors that a query or retransmission is required, the normal component combiner over the 20 hour period "missed" 14.4% of the total lines transmitted while the MVL "missed" only 2.3%. This technique certainly possesses potential and should be further pursued. Some type of MVL should be provided for that remote low speed TYC-5 installation.

Another area to examine in the HF area is the modem in the radio equipment. Most HF radio modems are capable of passing data at the 1200bps rate. There is a real requirement for passing data at even higher rates. In these cases the modem becomes critical. DCA has directed an operational comparison test and evaluation of HF modems for use in DCS systems. These tests are including data rates of 2400bps, 1200bps, dual 1200bps, 1200bps with in-band diversity and 2250bps (TADIL-A). In the testing the average BER shall not be greater than 1×10^{-4} for a 1200bps rate nor greater than 1×10^{-3} for a

2400bps rate with BER being defined as:

$$BER = \frac{\text{total number of errors}}{\text{total number of bits transmitted}}$$

These tests should be monitored for possible inclusion of the high speed modems into USMC HF radios that may be used with the TYC-5.

Additionally, various types of EDAC should be examined as possible means of obtaining better efficiencies over a HF path. EDAC has been shown to be very effective in lowering the BER. EDAC involves adding parity bits to the information stream, thus requiring an increased data rate over the transmission medium to maintain the specified information data rate or, if no increase is possible, a lower information rate must be accepted. Typically, half-rate codes are used although quarter and other rates have also been shown to perform well. A half-rate code would mean reducing the ultimate throughput rate by one-half.

The 24 bit Golay and short convolutional codes typically used are most effective against a random distribution of errors and do not perform very well when used directly on the HF media where errors tend to occur in bursts. For this reason, interleaving is included in most EDAC techniques. Interleaving involves storing many sequential bits and then outputting them in an entirely different order. This has the net effect of distributing the EDAC code words in time, hopefully having a time distribution somewhat larger than the longest fades or disturbances expected. On HF at 2400bps using a 24 bit Golay code,

an interleaving of about 100 is needed in order to have a significantly powerful code; and longer interleaving will continue to improve performance somewhat. However, the delay inherent in EDAC devices can degrade the throughput efficiency for the simple ARQ systems such as AUTODIN.

When there is a fairly short delay, no more than one block time, the AUTODIN terminal can operate in the continuous mode without wasting any time using two different ACK symbols to maintain a constant throughput. This mode breaks down to essentially a block-by-block mode when the round trip delay is longer than one block time. With EDAC the continuous mode is clearly the most efficient. If the round trip delay time, T_{RT}, at 1200bps were .56 seconds, the ultimate efficiency for a half-rate EDAC system is limited to E = .25 and .50 for block-by-block and continuous mode respectively. For T_{RT} = 1.12 seconds the efficiencies drop to E = .125 and .25 for block-by-block and continuous mode respectively.

Two conclusions can be made at this point: 1) continuous operation is more efficient than block-by-block operation for T_{RT} less than the transmission time of one block, and 2) T_{RT} should not be much larger than a block transmission time (.56 sec at 1200bps) if high throughput efficiency is to be maintained.

A difficulty caused by the long EDAC delay is that the AUTODIN time out timers are exceeded and then operation is no longer

possible. For best operation the AUTODIN time out timers should be set for slightly more than the round trip delay. The EDAC device must be carefully chosen to perform with the available time out constraints. At present the AUTODIN switches do not vary the time out timers to compensate for the transmission paths being used by various subscriber terminals.

The round trip delay, T_{RT}, discussed is composed of three contributions; the propagation time, the equipment delay time, and the EDAC device delay time. The propagation delay is approximately 5.4ms per 1000 miles of path length and is not likely to be more than 50ms for a round trip on any HF link.

The equipment delay is mostly a result of storage registers in the data equipment. Wireline modems cause two bit times delay each time a signal passes through them. Cryptographic equipment causes four bit times delay and the AUTODIN terminal constitutes another eight bits delay. HF modems cause approximately 14ms delay because of the 13.33ms frame time typically used plus storage register delay. In a study for DCA on the processing delay likely to be experienced in an ASC, Western Union reported a worse case two-way processing time delay of 146 bit times.

EDAC delays can range from fractions of a second up to many seconds. The one-way delay time for block and sequential codes will be discussed in a later paragraph. Essentially any delay

is possible by selecting the interleaving or constraint length. The permissible delay for an EDAC device will be calculated, given a desired throughput efficiency under normal AUTODIN operating rules, knowing the amount of time left over for EDAC delay.

For example, a typical HF link would have four wireline modems, two HF modems and two cryptos each one being passed through twice for a round trip. The total round trip delay time at 1200bps would then be about 289ms for a terminal to switch link and 199ms for a terminal to terminal link. In the block-by-block mode the throughput efficiency would never be better than .66 and .76 respectively. In the continuous mode the ultimate efficiency is 1.00 since the round trip delay is less than the 560ms degradation threshold. At 2400bps the continuous mode efficiency is still 1.00 but the block-by-block mode efficiency drops to .59 and .66 for the terminal to switch and terminal to terminal links respectively. Naturally, the efficiency will be degraded even further from these numbers due to errors on the link.

When EDAC is added, an additional delay must be included in the round trip time. Knowing the basic round trip delay times, an estimate of the EDAC delay time which can be tolerated so as not to excessively degrade the throughput efficiency can be made. The non-degrading terminal to terminal, continuous mode EDAC code on HF could therefore have a one-way delay of about 225ms.

The one-way delay of a block code is given by:

$$\text{time for one-way delay} = T_{ow}(\text{block}) = \frac{2mk}{\text{information data rate}}$$

where: m = interleaving bit length

k = number of information bits per block

n = EDAC code length

The information data rate is equal to $\frac{k}{n}$ x channel data rate where $\frac{k}{n}$ is 1/2 for the half-rate codes to be considered, so:

$$T_{ow} = \frac{2mn}{\text{channel data rate}}$$

The channel data rate in most cases using EDAC will be 2400bps, so:

$$T_{ow} = \frac{mn}{1200} \text{ seconds}$$

In the Golay (24, 12, 3) code, n = 24, so:

$$T_{ow}(\text{Golay}) = \frac{m}{50} \text{ seconds}$$

If 225ms one-way delay time on a HF circuit is not to be exceeded so as to maintain unity efficiency in the continuous mode, the Golay code interleaving may not exceed m = 11. Allowing the efficiency to degrade to no less than .75, permits extending the interleaving to m = 25. It can be seen that very powerful EDAC codes (with m being very large) would limit the efficiency considerably more.

A sequential or convolutional code one-way delay is given by:

$$T_{ow}(\text{seq}) = \frac{\text{constraint length}}{\text{information data rate}}$$

or for 1200bps AUTODIN RATE:

$$T_{ow}(seq) = \frac{lc}{1200} \text{ seconds}$$

where lc is the constraint length or length of the shift register used. To keep within the 225ms one-way delay time necessary for unity efficiency in the continuous mode on an HF link, the constraint length must be lc = 270 or less. Allowing the continuous mode efficiency to degrade to no less than .75 permits the use of codes with lc = 345 and .5 efficiency is reached at lc = 570. These are all illustrative figures, actual performance would depend on the actual link parameters.

It must be remembered that these delay limitations apply only to AUTODIN format systems with ARQ channel control from end to end. If other configurations are used, such as using a maximized throughput system, the delay limitations are removed and the longer, more powerful EDAC codes could be used.

Another area that NELC is looking into for the improvement of throughput within the existing AUTODIN constraints is by using a shorter block of data for the basic unit to be transmitted. The block size chosen for use by AUTODIN was due mostly to the common use of 80 column IBM punched cards. Over wireline links this block size proved to be a very appropriate choice. However, HF and some TROPO links are characterized by errors which occur quite frequently even though the percentage of bits in error is fairly low, and the probability of receiving 672 consecutive bits correctly is much less than

over a wireline. In order to combat this problem, shorter sized blocks can be used over the RF link, incorporating block parity, with synchronization and block numbering as required for each sub-block. In this way a larger percentage of sub-AUTODIN sized blocks can be assembled at the receive terminal per minute than is possible with AUTODIN sized blocks.

Because smaller block sizes are used, the round trip delay problem is magnified. To overcome this drawback, the transmit terminal must ensure that new sub-blocks are continually being transmitted, wasting no time waiting for acknowledges. To do this, the receive terminal must store received sub-blocks in correct order until all sub-blocks comprising an AUTODIN block have been received together. To overcome multiple retransmissions, a storage comparable to four round trip delay times is necessary to ensure an essentially constant flow of data. A small 16-bit mini-computer with no more than 8K of memory could handle this task easily at a fairly reasonable cost per terminal.

A short block system which adaptively seeks to maximize the throughput by choosing the optimum block size can also be used to select an EDAC coder to control errors during severe interference conditions and still be able to switch to an optimum block length without EDAC to maximize the ultimate throughput according to the present link conditions. A system which would be able to selectively

choose the best operating mode is the Maximized Throughput Store and Forward EDAC System (MAXSAFE) as developed by NELC. The link controller computer would require a memory consisting of 8K of 16-bit words when a separate EDAC coder is used. If the EDAC function were incorporated into the single controlling computer then 16K of 16-bit words would be more than ample for a fully automatic adaptable link controller system. Cryptographic equipments are also needed in order to decode the AUTODIN channel control characters. Two cryptos could be saved if the MAXSAFE system were incorporated into the existing AUTODIN terminals such as the TYC-5.

Although the MAXSAFE system incorporates several advanced data communication techniques, the effect on the operator can be quite minimal. Modern computers are versatile enough to operate in the several different modes, selecting the optimum mode based on information about the block error rate at the receive terminal and performing all necessary inter-computer communications without operator intervention. Again it must be pointed out that implementation of this type of system would require significant software changes within the AUTODIN switches and no actions are being taken to even investigate these possible techniques. [Ref. 1]

2. <u>Experiences</u>

Very little operational experience has been gained in the operation of high speed AUTODIN type operations over HF links. One

such link is a Mode I DSTE terminal at Naval Communication Station (NAVCOMMSTA), Harold E. Holt, N.W. Cape, Australia. That terminal operates at 150 baud over an HF link to the AUTODIN switch at Clark Air Force Base in the Philippines. Its efficiency or availability as calculated in the DCA format is shown in Table 8.

Table 8

Date 1973	Messages Sent	Recd	Total	Outages (hr:min) Ckt	Crypto	Term	Other	% Eff
Jan	1103	541	1544	181:00	-	-	-	75.67
Feb	1110	451	1561	239:27	3:00	3:10	-	63.44
Mar	1346	4444	1790	87:17	8:41	-	:16	87.60
Apr	1125	383	1508	38:20	4:11	1:06	-	93.94
May	737	219	956	108:21	6:49	11:18	:47	82.36
Jun	1185	415	1600	110:44	4:37	-	4:08	83.40
Jul	1110	568	1678	106:14	8:08	:27	:13	83.86
Aug	893	414	1307	86:30	4:09	:58	-	87.27

Even with the low data rates the percentage of time the circuit could meet those requirements were so low that they could not be depended on to support a tactical operation as envisioned the TYC-5 may well have to do.

Four different test situations were established by NELC for passing high speed AUTODIN type traffic over HF circuit paths. The first test actually utilized the TYC-5. The remaining three tests used a data generator and counted bit errors and translated them into the equivalent AUTODIN block errors.

The first test was a link from San Diego to 29 Palms Ca. The propagation path was by skywave, overland and for a distance of 125 miles. USMC AN/TSC-15 HF radio sets were used. The antenna configuration of both ends amounted to dipoles.

Two basic modes of operation were tested. The mode labeled "Diversity-dual Side Band" in Table 9 had a data rate of 2400bps. The full 16 tone package as delivered by the transmit modem was duplicated on the upper and lower side bands of the transmitter. The receiver was operated in the independent sideband mode and both sideband outputs were delivered independently to the receive modem for diversity combining. The advantage of this operating mode is that it gives the maximum date rate with one order of frequency diversity applied with a minimum of ancillary equipment required; only the data modem is needed - no extra receivers or antennas. The disadvantages of the mode lie in the necessity to divide the available transmitter power between the two sidebands and the requirement for a 6kHz frequency assignment.

The mode labeled "Diversity-Inband" has a 1200bps data rate and employed only a single sideband transmission. For this mode, the moden generated two 1200bps duplicate streams which were applied to the upper and lower 8 tones of the 16 tone package. The receive moden combined the 1st and 9th, 2nd and 10th tones, etc. in the in-band frequency diversity. This mode is advantageous in that all available transmitter power goes into a single side-band and only a

3kHz frequency assignment is required. The main disadvantage of the mode is its limit of 1200bps data rate. Results of the 12 data runs are summarized in Table 9.

The data runs that were not influenced by interference or adjustment problems were all very favorable for AUTODIN block transmission, nightime or daytime. The signal-to-noise (S/N) radio provided by the TSC-15 radio with the dipole antennas was adequate and the radio passed the 2400bps data without evidence of any residual error rate imposed by the equipment.

The factors influencing the transmission path should be considered very favorable for this test. Atmospheric noise levels were low in Southern California in the wintertime. The overland propagation path was also favorable in that the desert soil is of very low conductivity and the two hop skywave signal suffers a 6-19dB loss on reflection from the ground at mid-path. The one hop signal does not have a ground reflection and therefore aided in dominating the two hop signal. The skywave multipath problem is also mitigated. When S/N radio is adequate, multipath destortion is the major source of bit error in a 2400bps modem. [Ref. 1]

A second test was conducted during May and June of 1972. In that case simulated AUTODIN traffic transmission tests were conducted over a 270 mile HF path from San Diego to Vandenberg Air Force Base. The test path was over water, making it a more

RUN NUMBER	BIT RATE	DIVERSITY	TOTAL LINE BLOCKS TRANSMITTED	TOTAL RETRANSMITS (RETRANS)	% RETRANS	REMARKS
1	2400	Dual SB	1739	264	15	See run 2
2	2400	Dual SB	2480	766	31	Audio levels found out of adjustment
3	2400	Dual SB	1644	24	1.5	No apparent problems
4	1200	In-Band	1394	312	22	Severe interference
5	1200	In-Band	2479	164	6.6	New frequencies selected
6	1200	In-Band	1494	30	2	No apparent problems
7	1200	In-Band	1238	6	.5	No apparent problems
8	2400	None	2048	84	4	No apparent problems
9	2400	None	2366	182	7.7	No apparent problems
10	2400	None	2172	482	22	Simultaneous Voice
11	1200	In-Band	1367	64	4.7	Simultaneous Voice
12	2400	Dual SB	3508	374	11	Paper tape punch speeded up

TABLE 9

difficult path than the 29 Palms' test which was over desert. Lossless reflection of two hop skywave signals from the ocean aggravates the multipath problem predicting higher BER than observed on the previously tested desert path. In addition, a lightning storm, in the nearby coastal mountains during part of the June testing, led to a set of data which is representative of worst case conditions for that latitude

At San Diego, test transmissions were sent from a TSC-15 transmitter using a broadband dipole antenna. A digital test message was generated, fed to the HF data modem and the audio output of the modem fed to the TSC-15 radio. An EDAC processor (AN/USA-29) was arranged so that it could be included to encode the test message or be bypassed as needed. At Vandenberg a van was outfitted with Navy R-1051 communications receivers, HF modems, another EDAC processor and error counters. The error counters were arranged to count indicated bit errors and errors in the AUTODIN size block of 672 bits as well as in sub-AUTODIN size blocks of 1/2, 1/4, 1/8 and 1/16 size.

Two receiving antenna systems were set up for direct comparison of effectiveness in diversity operation. Two portable whip antennas spaced 400 feet apart comprised the space diversity antenna system. Two "tape measure" dipole antennas were erected with their axis' crossing at 90^{o} for the polarization diversity with dipole response.

Bit and block error data were taken over the test path for 16 hours a day, including day and night periods, with different modes

of operation being interleaved at 10-30 minute intervals to equalize the effect of changing path conditions on the performance of the modes under test. The following modes were studied:

1) space diversity with whip antennas

2) polarization diversity with dipole antennas

3) independent upper and lower sideband frequency diversity

4) single-sideband in-band frequency diversity

5) each of the above with half-rate EDAC applied

Preliminary estimates of the throughput were based on the assumption of randomly occurring bit errors. However, observed bit errors were seen to occur in bursts hence block error rates were lower than those predicted by random error formula. Random bit error rates of 10^{-2} and 3×10^{-3} were applied. For full sized AUTODIN blocks, the observed block error rate was considerably less than that predicted. Also observed was the fact that reduced block sizes did not yield the block error rate improvements as large as a random error curve would predict. Even though these results were from only two representative BER, a number of conclusions were reached. Most obvious is that the assumption of random errors over a HF path is very poor for estimating block error rates and system efficiency. Also important to note was the value of going to 1/4 block size as an attempt to improve throughput. As a BER of 3×10^{-3}, the efficiency was actually reduced by going to 1/4 size AUTODIN blocks. The

reduction in efficiency arose from having to use four times as many control characters and having the round trip time, T_{RT}, becoming greater than the duration of a 1/4 sized AUTODIN block. For AUTODIN block size traffic the continuous mode was slightly more efficient than block-by-block at BER of 3×10^{-3}. As the error rate increased to 10^{-2} the block-by-block mode finally became more efficient. In either case the difference between the modes was not significant. For 1/4 size blocks, the continuous mode was always the better of the two. These results are summarized in Table 10.

Table 10

Mode	AUTODIN Block Size	BER	System Efficiency Observed (%)
Block-by-block	Full	3×10^{-3}	47.6
Block-by-block	1/4	3×10^{-3}	32.8
Continuous	Full	3×10^{-3}	48.7
Continuous	1/4	3×10^{-3}	46.4
Block-by-block	Full	10^{-2}	17.8
Block-by-block	1/4	10^{-2}	20.9
Continuous	Full	10^{-2}	14.9
Continuous	1/4	10^{-2}	32.6

Throughput efficiencies were calculated for each of the diversity methods that were tested in both the block-by-block and continuous modes. Additionally the efficiencies for a shortblock/MAXSAFE system were calculated to include the effects of EDAC. For the full size blocks, the increase in efficiency for the block-by-

block mode over the continuous mode resulted from an erroneous block requiring only one block to be retransmitted rather than two. For full sized blocks without EDAC, the measured improvement in efficiency for the short-block system was 5-10%. Going to the 1/4 block size in the short-block/MAXSAFE system decreased the efficiency by a very slight amount for the usual error rates and improved the efficiency on the order of 10% for the higher average BER days. In the short-block/MAXSAFE system, the addition of EDAC appeared to be a substantial detriment for 1/4 size blocks. These comparisons can best be seen in Table 11. A direct comparison of the singular effect of EDAC can be seen in Table 12 where the fraction of time that EDAC efficiency for the different diversity conditions and BER exceeded non-EDAC efficiencies.

This particular test was probably the most in-depth study of high speed data transmission over HF paths conducted by NELC. [Ref. 1]

The first long haul HF test was from San Diego, Ca. to Hawaii, a distance of 2617 miles. The San Diego transmitter employed the TSC-15 with an average output power of 150 watts. The transmitting antenna was an unterminated sloping V with 300-foot leg length mounted on a 65 foot tower. This antenna was chosen as an example of one that could be easily put up in a few hours by military personnel in the field without any need for heavy equipment. At the Navy

EFFICIENCY OF TRANSMISSION OF AUTODIN BLOCKS AT 2400 BAUD

	DATE	AVERAGE BIT ERROR RATE	BLOCK-BY-BLOCK	BLOCK-BY-BLOCK W/EDAC	CONTINUOUS	CONTINUOUS W/EDAC	SHORT BLOCK/MAXSAFE NON-EDAC FULL	SHORT BLOCK/MAXSAFE NON-EDAC 1/4	SHORT BLOCK/MAXSAFE W/EDAC FULL	SHORT BLOCK/MAXSAFE W/EDAC 1/4
Polarization Div. Dipoles	24-26 May	3×10^{-3}	53.2	24.0	61.9	46.3	71.3	70.2	46.4	39.1
Independent SB Diversity	6-7 June	8×10^{-3}	34.5	23.4	35.9	44.5	46.3	55.7	45.3	38.9
Polarization Div Dipoles	6-7 June	6×10^{-3}	38.3	23.9	40.1	46.1	51.5	59.8	46.3	39.2
In-Band Diversity (1200 Baud)	8-9 June	4×10^{-3}	26.7	13.8	31.7	23.0	35.7	34.6	23.0	19.5

TABLE 11

FRACTION OF TIME EDAC EFFICIENCY WAS GREATER THAN NON-EDAC

	DATE	AVERAGE BIT ERROR RATE	CONTINUOUS	SHORT BLOCK/MAXSAFE FULL BLOCK	SHORT BLOCK/MAXSAFE 1/4 BLOCK
Polarization Diversity Dipoles	24-26 May	3×10^{-3}	.35	.16	.00
Independent Sideband Diversity	6-7 June	8×10^{-3}	.75	.60	.25
Polarization Diversity Dipoles	6-7 June	6×10^{-3}	.66	.42	.21
In-Band Diversity (1200 baud)	8-9 June	4×10^{-3}	.35	.21	.00

TABLE 12

Receiving Station at Wahiawa, Hawaii, the test signal was received on standard rhombic antennas and Navy R-1051 receivers. Spaced antenna diversity was employed for reception since it is a standard technique for Navy Shore Stations. Considerable attention was paid to the properties of the antennas used in this test. As much antenna gain as could reasonably be achieved in a portable antenna was desired to compensate for the low transmitter power output of the TSC-15.

Approximately a half million simulated AUTODIN blocks were transmitted from San Diego to Hawaii over a four-day period on four frequencies. If one or more of the 672 data bits in the AUTODIN block was received in error, the entire block was considered to be in error and was rejected. The data consists of the number of blocks in error as well as the BER in a 4-minute sample period. The data also includes the number of blocks in error for block lengths of 1/4 and 1/8 the size of AUTODIN blocks.

From this data, the efficiency relative to an error-free circuit can be calculated. For the block-by-block AUTODIN mode the efficiency is

$$E_{bb} = \left[(1 + T_{RT}/T_{BL})\ (1 - P_{BL})^{-1} + F_{cc} \right]^{-1}$$

for an instantaneous block error rate P_{BL}. The overall efficiency is obtained by integration of the above equation over time for the range of block error rates observed. T_{BL} is the time required to send one

block, T_{RT} is the round trip time including processing. F_{cc} is the fraction of the T_{BL} used for channel control, such as acknowledges in the reverse direction.

For the continuous AUTODIN mode, the efficiency is:

$$E_{cont} = \left[2(1 - P_{BL})^{-1} - 1 + F_{cc} \right]^{-1}$$

As before, the overall efficiencies calculated use the integrated form of the above equation.

Table 13 shows times and frequencies used and the observed block error rates. Table 14 condenses these data according to frequency and day/night data. These tables also include block error rates for 1/4 and 1/8 size blocks. All data are at 2400bps using spaced antenna diversity.

Most significant to note is that for the entire four days data, the block error rate was only 7.2%. This block error rate would yield an overall efficiency of 85% that of an error-free circuit. Daytime conditions are extremely steady, block error rates range from 4-14%. At night the block error rates ranged from 0.5 to over 25% with large short period variations. This day/night variability will be typical of almost any HF propagation path.

The BER for 16.1 and 6.9MHz are phenomenally low; 50% of the time they were less than 9×10^{-5} on 16.6MHz. On 6.9MHz the median error rate was 3×10^{-4}. The excellent error rates were

DATE	HST Times	FREQUENCY	% BLOCKS IN ERROR AUTODIN BLOCK SIZE FULL	1/4	1/8
7 Nov	1420-1620	16.1MHz	9.5	3.6	2.0
8 Nov	0804-1510	16.1	6.8	2.0	1.1
	1744-2100	6.9	8.3	4.7	3.2
	2308-0024	6.9	13.3	6.8	5.3
9 Nov	0025-0304	4.1	12.5	5.3	3.6
	0828-1630	16.1	4.3	1.6	1.0
	1706-1750	8.0	3.9	1.5	1.2
	1750-2044	6.9	7.0	3.4	2.5
10 Nov	0840-1650	16.1	3.2	1.1	0.6
	1700-1808	8.0	3.4	1.3	0.8
	1920-2140	6.9	11.2	5.5	3.7
	2156-2330	4.1	19.4	9.3	5.5

TABLE 13

SAN DIEGO-HAWAII TEST DATA SUMMARY

FREQUENCY	% BLOCKS IN ERROR AUTODIN BLOCK SIZE FULL	1/4	1/8
16.1MHz	5.1	1.7	1.0
8.0	3.6	1.4	1.0
6.9	9.2	4.7	3.3
4.1	15.6	7.1	4.5
All Daytime Data	5.1	1.7	1.0
All Night Data	9.9	4.8	3.3
ALL DATA	7.2	3.0	2.0

TABLE 14

attributed to high gain and mode rejection from the antenna pair used and the diversity spaced receiving antennas. The efficiencies calculated from the block error computations were very high. 90% of the time the efficiency was greater than .82 on the 16.6MHz and .67 on 6.9MHz. 50% of the time the efficiencies increased to .92 and .88 for the two frequencies respectively.

A check on the advantages of a diversity rhombic receiving antenna system was made during steady daytime conditions on 16.1MHz. Single channel rhombic and omnidirectional (monopoles) antenna diversity were compared with diversity rhombic data. Switching from single channel to diversity rhombics improved the observed BER by an order of magnitude and the block error rate from 18% to 3.7% Using diversity monopoles instead of rhombics increased the BER by a factor of five and the block error rate from 3.7% to 7.4% for full size AUTODIN blocks. The importance of diversity is obvious. The best HF antenna (a rhombic) performed poorer than diversity monopoles having no gain or directivity. [Ref. 4]

The final test in the series was a San Diego to Guam HF test that was designed to determine the optimum conditions for passing AUTODIN data over a very long path (6200 miles) with low power tactical equipment such as the TSC-15. Since low power was used, from the onset it was not expected that the circuit could be maintained on a 24 hour basis. During the test half-rate coding was used as a possible method of improving the transmission efficiency.

Previous NELC calculations had shown S/N ratios could be extrapolated to estimate system efficiencies: 55, 60, 65 and 70dB would yield efficiencies of 30%, 60%, 82% and 92% respectively. The frequency predictions for the test path showed that between 2100 and 0300 GMT the S/N ratio is less than 60dB on any frequency and the resulting efficiencies would be 60% or less. This marginal six hour daytime period is due to primarily D-layer absorption causing inadequate S/N ratios for the 3-5 hop propagation mode. This period, however, can show great variations. During the remainder of the day, efficiencies were predicted to stay at 75% or higher and would be degraded only by other user interference or possible multipath propagation problems.

Over two million simulated AUTODIN blocks were transmitted at 2400bps over the test period on five frequencies. If one or more of the 672 bits in a block were received in error, then the entire block was considered to be in error and was tabulated as a block error. From that data, the efficiency of the circuit was calculated. This efficiency was the percentage of new information bits relative to the total number of bits transmitted. Efficiencies, as calculated in this particular test, could not exceed 95.4% since four out of every 84 characters in an AUTODIN block is for channel control and cannot contain data. If half-rate coding is used then the efficiency cannot exceed 47.7% since half of the transmitted bits are used for error

detection and correction. Using previously developed formulae for calculating the efficiency and integrating that over time, the following overall efficiencies were determined:

For single channel uncoded	25.8%
For single channel coded	46.1%
For diversity uncoded	76.2%
For diversity coded	47.5%

Recall that the efficiency of coded data cannot exceed 47.7% because half of the transmitted bits are coding and not information. Clearly, for this particular set of data, the uncoded diversity mode is the most efficient.

From the above data and the efficiency formula, the single channel coded data would become more efficient than uncoded diversity data when block error rates exceed approximately 45%. Coding of diversity signals would become more efficient than uncoded at block error rates in excess of about 35%.

The availability of coding should suffice to keep efficiencies at 40% or greater during the day. It was felt that had a large number of frequencies been available to select from, interference could have been avoided and operation near the optimum frequency for the given daytime hour could have been performed. Under those conditions efficiencies of 60-70% should be achievable.

It was not expected that this very long path low power system would be implemented to handle data on a continuous basis without

high throughput. Yet this test showed that about 1000bps of information (40% efficiency) can be achieved almost anytime using half-rate coding and a transmission rate of 2400bps. Even higher efficiencies result at times when coding is not required. [Ref. 5]

3. Expected Reliability

The expected reliability of an HF circuit must be computed by normal frequency prediction measures. Regardless of which set of tables are used, a maximum usable frequency (MUF), lowest usable frequency (LUF) and the frequency for optimum transmission (FOT) are calculated. Some computer programs will now generate tables that will shade the area about the FOT and even predict probabilities for the reliability of that particular frequency. The realistic difficulty, of course, is obtaining the desired frequency once it is properly calculated. The converse is accepting the low reliability if assigned only a certain frequency.

4. Expected Efficiency

The results of the various tests indicate a minimum efficiency of 40% or 1000bps of new information at a 2400bps transmission rate using half-rate coding. Additionally efficiencies can be expected to increase markedly when switching from a single antenna to a diversity antenna system. Major impacts on efficiency are: proper choice of frequency, antenna diversity and, if a very bad circuit path exists, EDAC.

5. Operational Parameters/Constraints

The major operational constraint today appears to be the availability of clear frequencies. This is further complicated if "dual side-band diversity" is used and 6kHz allocations are then required. The frequency support for a remote AUTODIN terminal must be given absolute priority for the frequency assignment.

Another operational constraint involves the conversations with the ASC. Although in test configurations data can be pushed through marginal HF paths and efficiencies can be calculated, the AUTODIN constraints are not very lenient. It was determined that bit errors are not normally distributed but appear in bursts. Present AUTODIN procedures call for a maximum of three attempts to send a line block. After that an alarm condition exists and a manual intervention is required. Basically the switch assumes the circuit is out if three consecutive attempts can't get a line block through. The AUTODIN software must be addressed in this area and provide some relief to terminals operating via HF links.

A rather unique cost constraint comes into play also. BER increases with the transmission rate, however at a higher transmission rate, less time is required to resend a block that was in error. However, this is not a linear function. If, as previously stated, 40% efficiency (1000bps) is the minimum to be expected on a 2400bps link, an increase to 4800bps would not increase the new

information rate to 2000bps. The counter is also true, at 1200bps transmission rate, an efficiency producing greater than 500bps of new information would be expected. The RF path is somewhat free of charge regardless of the transmission rate, however, the extension of the circuit from perhaps a NAVCOMMSTA to an AUTODIN switch may well be over leased communication lines. The cost of these communications lines used as AUTODIN access or subscriber lines is not a linear function for increasing transmission rates. A doubling of the transmission rates to allow for half-rate coding to obtain a relatively small increase in new information throughput may increase the cost of the landward extension of the circuit by 75%. This then would not be a logical move unless a specific data rate (e.g. TADIL-A) was required.

IV. TERMINATION RESPONSIBILITIES

A. AUTODIN TERMINALS

The providing of an AUTODIN terminal is a user responsibility. In this particular case it is a Marine Corps responsibility. If a leased terminal is to be used, the Marine Corps has the responsibility of stating and justifying the requirement. Within the Department of the Navy, Naval Telecommunications Command (NAVTELCOM) acts as the major claimant for those funds required for leased communication equipment and services.

In DEPSECDEF memo of 5 March 72 Subj: Policy for AUTODIN, AUTOVON and AUTOSEVOCOM Service, under paragraph 8. Subscriber Access, we find "a. the DOD components, other government agencies and other activities will determine operational requirements, provide and operate subscriber equipment for those activities for which they have support responsibility."

The Marine Corps has seen the coming trend of high speed data requirements and sees AUTODIN as the means of meeting these requirements. The Marine Corps also saw the cost in dollars and in extended installation time to provide leased commercial AUTODIN terminals as was done in Viet Nam. To address these problems and to assume the responsibility outlined in the DEPSECDEF memo, the Marine Corps procured the TYC-5.

Included in providing an AUTODIN terminal is the responsibility to provide the local support required for the terminal. This includes power, environmental conditioning and necessary ancillary or supporting equipment.

B. TRANSMISSION MEDIUM

The responsibility for the transmission medium can vary. If an existing DCS network is available a rather simple Telecommunication Service Request (TSR) to DCA will provide the necessary channel. These TSRs are submitted by NAVTELCOM upon the approved request for service from the Marine Corps. If an established network or system is not readily available, certain varied responsibilities are encountered. OPNAVINST 5450. 184A of 16 October 73, subject: Commander, Naval Telecommunications Command; mission and functions of, lists as one function "f. Coordinates and develops plans and programs in support of Marine Corps landing force long haul external communications requirements for entry into the Naval Telecommunications System and the Defense Communications System." NAVTELCOM can meet these responsibilities in different ways. Possible solutions would be deployment of Navy Air Transportable Communication Units (ATCU), requesting all or portions of the Defense Communication System Contingency Station (DCSCS) or looking for some commercial lease arrangement. The responsibilities for

maintaining these different systems is widely split. Additionally the responsibility for determining the required capabilities of these systems is not very clear. The commercial systems will provide almost any capability required given the dollars and time. The ATCU and DCSCS have certain designed capabilities but little flexibility. The design capability for the ATCU is primarily to support a group of 75 baud teletype channels over an HF link. The DCSCS is quite similar except it also possesses TROPO and micro-wave capabilities and probably will possess satellite capability in the near future. The DCSCS has recent additions of terminal equipments capable of working with AUTODIN; one DSTE Mode I terminal capable of 150, 300, 600 or 1200 baud operation and two Mode V terminals operating at 75 baud. These are presently envisioned as operating over the micro-wave or cable capabilities of the DCSCS and perhaps satellite in the future. Neither the ATCU or the DCSCS is specifically designed to provide a transmission medium for a high speed AUTODIN terminal like the TYC-5. The Navy maintains a small number of ATCUs. The Army, Air Force and Navy each maintain one DCSCS for operation under JCS tasking.

C. AUTODIN ACCESS

A great deal of the responsibility lies with DCA. DCA has the responsibility to maintain system integrity and system standards. Presently DCA facilities, the AUTODIN switches, are only equipped

to terminate subscribers operating over cable or micro-wave. There are no other transmission facilities available or planned for. Even the DCSCS is planned to terminate with a military service facility where the signals will be transferred to landline or a cable for extension to a DCS AUTODIN switch. Under these circumstances, any changes in system design is cable or micro-wave interface oriented. The message format, signal levels and signalling are also determined and maintained by DCA.

The much earlier established doctrine of the amphibious force flagship acting as a gateway for the amphibious force ashore to enter the Naval Telecommunication System or DCS is no longer appropriate. Although data links that can handle high data rates can be established from the beach to the flagship, the flagships have no means of relaying this high speed data to a NAVCOMMSTA. Perhaps shipboard satellite terminals in the future will allow a reexamination of this doctrine.

V. SHORTFALLS

A. AUTODIN TERMINAL

The lack of the message center configuration to provide support fôr the TYC-5 is the biggest shortfall in the terminal area. Without some improvement in this area, outgoing traffic will be as limited as it was over the previous manual 100wpm teletype circuits.

The environmental support of the TYC-5 and its supporting equipment, including a transmission system, is a rather weak area. The MUSE generators and design and provisioning of additional air conditioning and humidity controls are needed.

The basic TYC-5 appears to be adequate for its intended applications.

B. TRANSMISSION MEDIUM

Minor shortfalls appear in each of the transmission mediums addressed, major shortfalls exist in some. In the area of cable and landline the shortfall existing is the state of neglect into which cable installation equipment and techniques have fallen. Only through more schooling and investment in newer equipment can this be remedied.

In the area of micro-wave, the need exists for some type of tower for field installations requiring greater heights than afforded

by the existing TRC-97 masts. The tower AB-216 was mentioned before as a possible solution to this.

The area of TROPO operations requires equipment in excellent condition. The tests indicated that most of the circuit time unusable for passing traffic was attributable to equipment problems. Additionally, the propagation is such that some technique or application of EDAC is most desirable. This capability is not readily available now.

In the area of HF transmissions we find a number of factors required to obtain a path capable of sustaining high data rates. The first is frequency assignments. The present policy of assigning only a minimum number of 3kHz frequencies to support a high speed HF link does not provide sufficient flexibility to determine the FOT for a given time and have that frequency available. Also needed for improved high speed HF links are high speed modems such as those that are being tested for DCA. Since diversity methods are most impressive in reducing error rates, HF systems should be configured to allow for different diversity conditions, e.g. antenna, polarization, in-band frequency, etc. To compensate for a burst of interference that may affect all the diversity means normally employed, perhaps a system of time diversity could be developed to span any particular burst of interference. If ordinary combiners are unable to handle the variety of diversity methods needed, a majority vote logic (MVL)

may be required/desired. Over certain paths EDAC may also be required and it is not now readily available within the Marine Corps operating forces. One critical shortfall existing is within the AUTODIN software. The present policy of attempting to send the same block of information up to three times before the system faults, is not adequate for high speed data over HF. Although the fault condition can easily be reacted to, it does require a manual intervention. In high speed transmissions, a burst of interference may exceed the time required to send the three line blocks and an artificial fault condition will arise. A software patch in the ASC program is required. It must acknowledge the uniqueness of a subscriber operating at high data rates over HF and allow many more attempts to resend a block of information that was in error before a fault condition exists. Since the original three attempts was based on 100wpm teletype channels, 20-25 attempts at 1200bps should not be excessive. If all other techniques of stabilizing the circuit path and reducing the BER are in effect, these repeated attempts to send a block that was in error will seldom require over 3-5 attempts.

Satellite systems are most difficult to address in regard to shortfalls since the specifics of the satellite systems are not yet firm. Care should be taken to ensure the satellite terminal equipment is compatible with the TYC-5 and made available to support the TYC-5. The difficulties previously addressed concerning the

time delay over the long circuit path must be addressed again. Field tests indicated that by allowing up to seven line blocks to be transmitted before requiring the first acknowledgement, speeds in excess of 1200bps could be maintained. DCA must provide a software change to the ASC program so that the switch can adapt to subscribers that are terminated via satellite. It must identify them and be prepared to buffer up to seven line blocks in order to properly space the acknowledgement signal to allow for high data rates.

Transmission systems as a whole, and specifically the ATCU and DCSCS must be restructured to provide for high data rate support in the area of 1200-4800bps. These systems are still 100wpm teletype oriented.

C. AUTODIN ACCESSIBILITY

The two software changes for HF and satellite must be made. Additionally the amphibious force flagship capabilities must be increased to allow for its role in supporting high speed data traffic requirements from the landing force ashore. Specifically the subsequent relay of this data to external systems must be addressed.

VI. CONCLUSIONS

A. PREFERRED AUTODIN CONFIGURATION

The TYC-5 appears to be a most adequate AUTODIN terminal. This equipment coupled with an adequate message center capability and the TGC-37 should be employed using cable or micro-wave into AUTODIN for the best results. These configurations provide for the fewest errors and greatest throughput efficiencies. When satellite means are fully developed and implemented, satellite may well become the preferred mode of transmission. HF and TROPO capabilities should be developed and maintained but only to augment the preferred systems.

B. CRITICAL SHORTFALLS

Although each of the shortfalls previously discussed reduces the capability of the TYC-5 to act most effectively as an AUTODIN terminal, two shortfalls can be singled out as most critical.

1) The need for a transportable message center to accompany the TYC-5 is overwhelming. To provide the terminal and transmission capability to handle high data rates yet not provide the traffic handling capabilities at the terminal site is illogical and wasteful of unique capabilities.

2) The inflexibility of the AUTODIN switch to make minor accommodations to subscribers terminated over other than cable/ micro-wave systems strongly curtails high speed data terminations over HF and/or satellite links directly with the ASC. The software changes previously discussed are required.

VII. RECOMMENDATIONS

It is recommended that:

1) the Marine Corps pursue the development of a transportable message center to support the TYC-5.

2) the Marine Corps and NAVTELCOM jointly urge DCA to make the necessary software changes to allow HF and satellite link terminations to work more effectively as previously discussed.

3) the Marine Corps reevaluate the power and environmental support systems for the total communications complex.

4) the Marine Corps reinstate a concern in cable installation techniques to include providing the required trained personnel and equipment to the operating forces.

5) the Marine Corps procure 4 towers AB-216, for each Communication Battalion for use with micro-wave links as required.

6) the Marine Corps explore possible EDAC equipment for use with TYC-5 transmissions over TROPO or HF.

7) the Marine Corps establish priorities with NAVTELCOM for the assignment of HF frequencies to support TYC-5 applications over that medium.

8) the Marine Corps examine the possible diversity conditions and the necessary combiner or MVL units in any new HF radio equipments to be procured.

9) the Marine Corps and NAVTELCOM closely monitor the development of the high speed HF modem by DCA for possible inclusion in tactical HF radios (to include the ATCU) used to support the TYC-5.

10) the Marine Corps closely monitor all satellite programs that can possibly support the TYC-5 to ensure compatibility of equipment and availability of service.

11) the Marine Corps and NAVTELCOM ensure that the requirement for high speed data transmission from remote areas via amphibious force flagship, ATCU and DCSCS is known, so as to be included in modification or development of these systems.

12) the Marine Corps look forward to the time when all the transmission medium discussed in this paper are readily available to the user in the field, and develop a means of assisting the user in selecting the proper transmission means. A technique similar to that shown in APPENDIX C could be used.

APPENDIX A A Proposal for Supporting the TYC-5

The TYC-5 must be thought of as basically a Mode I multi-media AUTODIN compatible terminal. There is relatively little room inside its shelter for physical expansion but a great deal of room and flexibility for interfacing or system expansion.

The initial concept of the TYC-5 saw it as the AUTODIN terminal in a three component complex. A second component was the TGC-37 which is a teletype, torn-tape relay van. The TGC-37 is basically configured to terminate approximately six, 60wpm half-duplex teletype circuits to subordinate units and relay traffic between them via torn tape methods. Traffic destined for outside that community would leave the TGC-37 over a 100wpm full-duplex circuit. This circuit could go to an AUTODIN switch in a Mode II configuration or to a higher unit processing center. The latter idea was most prevalent. That higher unit processing center would also have a TYC-5 in conjunction with it. This then would provide high speed AUTODIN access and lower speed distribution to subordinate units via the TGC-37. The TYC-5 and TGC-37 were developed and procured, the higher unit processing center does not exist.

In the terminology of Naval Communications, the TYC-5 and TGC-37 provide the transmitting and receiving portions of the

communications center and the portion of the communication center missing is the message center. The typical functions required of a message center include logging and checking messages, routing indicator look-up, paper tape preparation, message reproduction, filing and distribution, and some type of file retrieval. In all operational experiences with the TYC-5, up to this point in time, buildings have been utilized to house these functions. Initially in Thailand strong backed screened tents were used but the heat and dust created extreme equipment maintenance problems. Even after moving into more permanent structures the teletype message preparation and routing indicator look-up continued to be weak links in the overall message transmission system.

Every indication points to a renewed requirement for some type of transportable message center facility. This message center should be built around three sub-systems: 1) message entry, 2) message distribution and 3) message management and control.

The same requirements for message entry systems exist in the tactical environment as well as the garrison situation. Efforts in the development of the Local Digital Message Exchange (LDMX) within DOD has addressed message entry systems in detail and provide for nearly fully automated message entry. To benefit from work done in LDMX development and to comply with existing DOD directives that prescribe the DD-173 message form as the only form to use

within DOD, the DD-173 should be adopted for field use. Various USMC automated systems have already caused optical character recognition (OCR) font typewriters to be distributed throughout the operating forces. These OCR font typewriters and the DD-173 provide a ready basis for automated message entry.

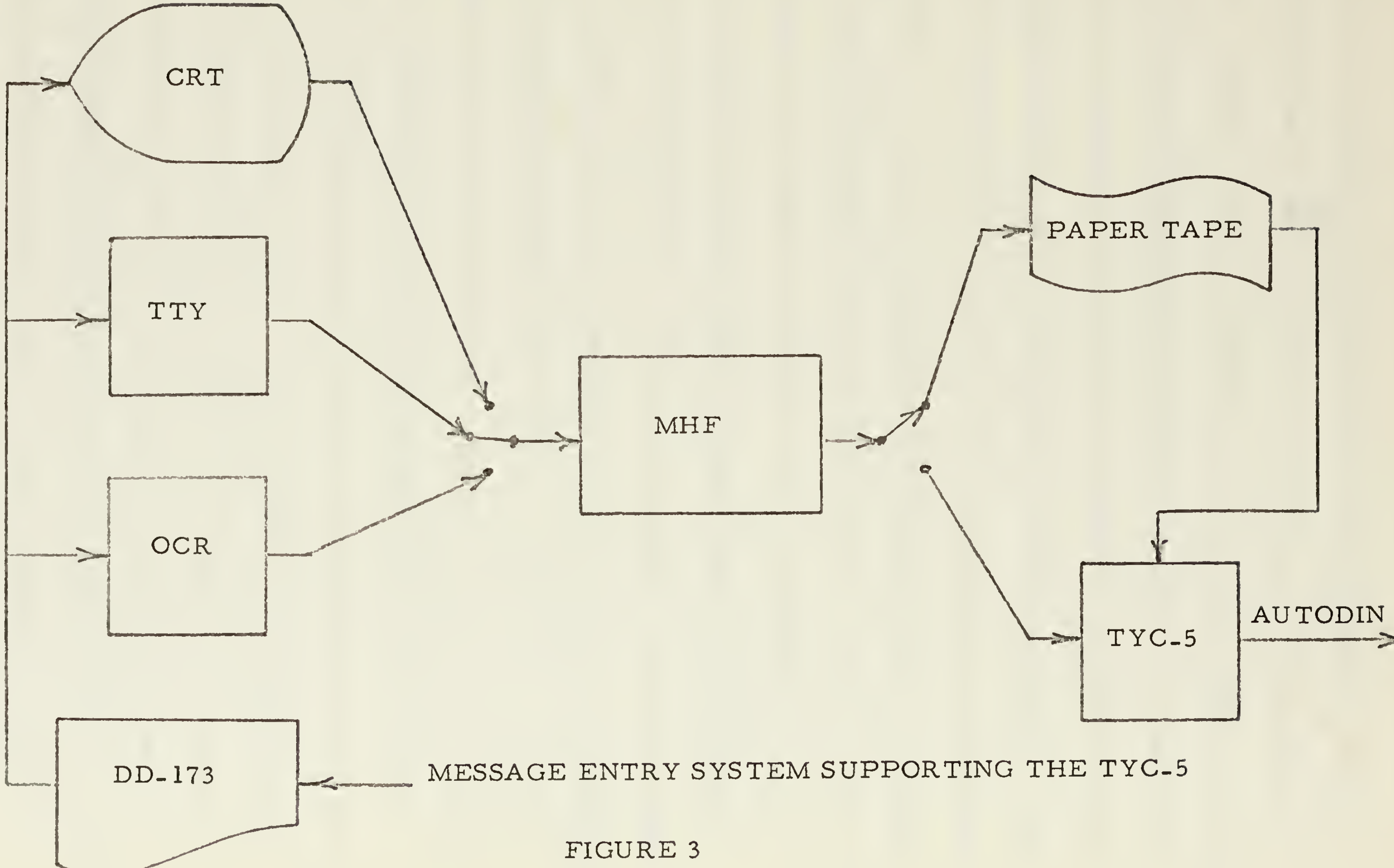
There are three basic functions in message entry: 1) routing indicator look-up, 2) message formatting and 3) translation of the written or typed message into a machine or system sensible language. These can best be performed in a two device configuration. An OCR device would accept the DD-173 and translate the plain address of the message into inputs for a second device, a message header and formatting device, for a table look-up. The message header/formatter (MHF) would compare the plain language address with pre-stored communication routing indicators (RI) and select the proper RI. With this plus the other drafter information of the DD-173 such as classification and precedence, the MHF could generate the header portion of the message in accordance with the prescribed JANAP-128 procedures. Since AUTODIN is fully automated and quite complex, the system will not accept errors in the message heading. The MHF could preclude these errors that normal manual operators are prone to insert periodically. The OCR could then translate the textual portion of the message and finally an end of message indicator. The MHF would take the end of message indicator and provide the necessary

formatting to comply with JANAP-128. The message in its entirety could then be sent over AUTODIN or punched out on paper tape to be sent over AUTODIN. The TYC-5 has sufficient ports on its AUTODIN interface unit, to enable direct connection of the message entry system and the TYC-5.

For possible error corrections, editing or the adding of special RI that are not programmed due to low usage, a cathode ray tube (CRT) and/or a teletype (TTY) position would be used in conjunction with the MHF/OCR complex. Figure 3 shows these relationships.

The message distribution system becomes more complex. Part of the complexity is caused by the varying requirements. The distribution may be as limited as providing one copy of each incoming message to the duplication center or as diverse as selected internal message routing to certain staff sections of a headquarters and to subordinate or tenant units. Although very detailed message distribution has been addressed in LDMX development, all solutions appear to be very costly. At least costly in the amount and cost of software required for determining the final addressee of a message.

In a tactical environment the organization and missions change so rapidly that the more static standard distribution algorithms used in the LDMX may not work well. A more basic approach is required. Incoming message traffic should be routed to a combination of only six destinations. All magnetic tape incoming traffic should go to



MESSAGE ENTRY SYSTEM SUPPORTING THE TYC-5

FIGURE 3

one destination, either within the TYC-5 and hand carried to the customer or remotely delivered to that one designated customer. All punched card traffic should be routed to one card distribution point. Various card users would pick up their card traffic at the one point, which would probably be in the message center. One position within the message center should be designated to receive very high precedence and very high security level narrative messages. This position would require interactions with the central message distribution system to ensure that properly cleared personnel were manning the terminal when high security level traffic was received. Very high precedence level traffic but of lower security classification would also be routed to a remote printer (receive only) in the operations center of the headquarters. All narrative traffic, with the exception of very high security level messages, would be routed to a distribution center within the message center facility. At this point, the means of final delivery and the assignment of action responsibility would be made. In the case of very high precedence traffic, this delivery would be a normally distributed back-up to the advance copy electrically sent to the operations center. The distribution center can use the normal methods of message reproduction, collation and assignment of action offices as outlined in Naval Communications instructions. A further automated possibility exists within the Marine Corps. A great deal of research and testing has been done to develop a Digital

Transmission and Switching System (DTAS) for the Marines. One extreme configuration of DTAS could provide for small teleprinter terminals at most offices within a headquarters. Additionally, subordinate units can also be accessed. The switching is done according to prescribed DTAS addressing schemes. If access were made to DTAS at the distribution center, then perhaps with a CRT, a distribution operator could assign action, determine internal distribution, insert appropriate DTAS addresses and provide for final distribution via DTAS. This could preclude a requirement for centralized message reproduction.

The sixth destination for message delivery within this concept would be narrative message traffic received over the TYC-5 but addressed to either subordinate or tenant activities that are electrically connected either directly to the message center or via the TGC-37. In these cases, direct electrical delivery should be made and no manual message distribution should be involved.

Message management and control is somewhat of a catch-all, but none the less a most necessary function of the message center. One of the functions included here would be traffic statistics and reports. A system of generating reports over given times showing messages and line blocks both transmitted and received is required. A master clock should be included in the system to identify the time in and time out of all message traffic. A most important part of this sytem would

be a message file system. If a tradeoff in cost and size versus access speed were conducted, the cost and size of the message center would probably prevail and a sequential magnetic tape message file system would be maintained. It would include the complete message for all narrative messages and the header and trailer information only for all data pattern magnetic tape or punched card messages. The file system would be available for message retrieval as required. Messages should be retrievable on the basis of: 1) date-time group, 2) message originator's RI, 3) internal station serial number and 4) combinations of these.

Correlating the features of message input, message distribution and message management is included in control. This would provide for the edit/display stations to act as primary system processing control points. The control would of necessity have self imposed diagnostic routines to identify down portions of the system.

The message center facility must fulfill the above requirements, and must be installed in one or more transportable field shelters for rapid deployment and ease in installation. The shelters should be compatible with the vans utilized with the TYC-5 and TGC-37 to allow for an operational shelter complex. Environmental controls needed for the message center facility must be included in the design.

APPENDIX B The ARPA Network

The Advanced Research Projects Agency (ARPA) network is a nationwide system designed both to explore network technology and to interconnect and service ARPA-sponsored research centers. The key aim of the system is to allow the accessing of programs, services and data from any place on the network.

The ARPA network is a distributed network; sites or nodes of the network are connected to each other either directly or indirectly through intermediate sites. This is to be distinguished from a centralized network when all sites are connected together via one central site. The computers and associated software systems that make up the ARPA network are heterogeneous, not all from the same source.

The network can be broken into two parts. One part consists of the computers which will provide the computational services of the network - the hosts: the other part deals with the function of servicing the communication needs of the network.

The communications section of the ARPA network consists of modified Honeywell DDP-516 computers connected via 9 and 50 kilobit leased telephone lines. The DDP-516 machines are called IMPS (Interface Message Processors). The communication system operates in a mesage-oriented store-and-forward fashion: a message is stored

at intermediate points as it makes its way toward the destination. Each time the message is handed forward correctly, the handing node is freed from any further responsibility for the message. Since it is often necessary to send messages of substantial size, the network breaks long messages into smaller sub-messages called packets. These packets of about 1,000 bits are independently forwarded through the communications network. A duty assumed by the network, through the IMPS, is to ensure that the packets are reassembled into the original message for transmission at the destination host. The IMPS also govern routing of messages through the network in order to minimize the transit time of the message and to increase the utilization of the transmission facilities. [Ref. 6]

For purposes of routing, each node maintains a list which contains for each destination an estimate of the delay a message would encounter in attempting to reach that destination node were it to be sent out over a particular channel emanating from that node; the list contains an entry for each destination and each line leaving the node in which this list is contained. Every half second (approximately) each node sends to all of its immediate neighbors a list which contains its estimate of the shortest delay time to pass to each destination; this list therefore contains a number of entries which is one less than the number of nodes in the network. Upon receiving this information from one of its neighbors, the IMP adds to this list of estimated delays a measure of the

current delays in passing from itself to the neighbor from whom it is receiving this list; this then provides that IMP an estimate of the minimum delay required to reach all destinations if one traveled out over the line connected to the neighbor. The routing table for the IMP is then constructed by combining the lists of all of its neighbors into a set of columns and choosing as the output line for messages going to a particular destination that line for which the estimated delay over that line to that destination is minimum. [Ref. 7]

The network specification requires that the delivered message error rates be matched with computer characteristics, and that the down-time of the communications system be extremely small. Three steps have been taken to ensure these reliability characteristics: 1) at least two transmission paths exist between any two modes, 2) a 24 bit cyclic check sum is provided for each 1000 bit block of data and 3) the IMP is ruggedized against external environmental conditions and its operation is independent of any electromechanical devices (except fans). So far, the downtime of the transmission facility has averaged 2.3% outage for each line, however, the duplication of paths reduce the average downtime between any pair of nodes, due to transmission failure, to approximately 0.4%. The cyclic check sum was chosen based on the performance characteristics of the transmission facility; it is designed to detect long burst errors. The code is used for error detection only, with retransmission on an error. This check reduces the undetected

bit error rate to one in 10^{12} or about one undetected error per year in the entire network.

The target goal for responsiveness was 15 seconds transit time from any node to any other, for a 1000 bit (or less) block of information. Actual response averages .1 second for 1000 bit blocks and .3 seconds for 8000 bit messages for all traffic levels less than saturation. After saturation the transit time rises quickly because of excessive queuing delays. However, saturation is avoided by the net acting to choke off the inputs for short periods of time, reducing the buffer queues while not significantly increasing the delay. [Ref. 8]

There are currently 23 host machines on the existing ARPA network. These range from a PDP-11 through the ILLIAC IV. The network is managed by the ARPA agency and is technically directed by a steering committee of the Network Working Group, an organization of host representatives who are charged with the technical evolution of the system.

The ARPA network is today the main candidate for becoming a nationwide data network

APPENDIX C Management Information System (MIS) Handbook

This MIS handbook is for selecting the proper transmission medium to support the TYC-5. The element of the MIS for the determining of the best transmission medium from the TYC-5 to the ASC for conveying the types of information required will be identified and a ranking by importance will be made. Any dominance will be identified and a reasonable weighting will be assigned to each element of information. Some elements of information will be weighted heavier or lighter at different echelons of planning. The following elements will be discussed: (listed in order of importance)

1) Distance between the terminal and the ASC
2) Availability of material support
3) Level of qualified personnel available
4) Power sources available
5) Presence or absence of hostile areas between the terminal and the ASC
6) Presence or absence of geographic barriers between the terminal and the ASC
7) Transmission speed requirements
8) Reliability requirements
9) Length of termination period

10) Radio frequencies available

11) Predicted rainfalls

12) Predicted snowfalls

13) Efficiency requirements

14) Humidity ranges present

15) Vegetation in the area

16) Predicted winds

17) Whether or not the TYC-5 is terminated with a Naval Communications Station (NAVCOMMSTA)

18) Sites available

19) Temperatüre ranges present

20) Predicted freezes/sleet

The levels of planning to be addressed are:

1) The Fleet Marine Force (FMF) - the highest level of tactical planning

2) The Marine Division (DIV) - the lowest ground unit supported by the TYC-5

3) The Marine Division Communications Company (CommCo) - the lowest ground unit employing the TYC-5

A weighting notation will be associated with each element. First an overall weight will be assigned to the element on a 1-10 scale. Then to show the different weightings by level, a graduation of 1-3 will be indicated for FMF as F, DIV as D and CommCo as C. E.g. an

important element with FMF placing a great deal of weight on it, DIV placing normal weight on it and CommCo almost ignoring it. The notation would be:

Weighting: 9, F-3, D-2, C-1

The MIS is to aid in decision making by reducing risk. By looking at the twenty elements and placing the relative effort, as shown by the weighting factors, on gathering the information for that element, the risk in the final decision, i. e., selection of the right transmission media for the given case, should be greatly reduced.

Each of the elements follow as a separate item. They form the heart of the MIS handbook and would allow the decision maker to work strictly from them given a certain decision to be made and the key to the weighting notation.

1) Distances Involved

In discussing distances between the AN/TYC-5 site and the AUTODIN ASC we can identify certain transmission means whose employment is dominated by this one element. TROPO is pretty well limited to less than 200 miles, therefore TROPO will be ruled out at all planning echelons if the distance exceeds 200 miles. Micro-wave transmissions operate in the ultra high frequency (UHF) or super high frequency (SHF) range and as a result must be in a "line-of-sight" configuration. A nominal range of less than 40 miles is usually used at all planning echelons and distance again is a critical element.

Cable limitations also exist with distance. A cable without any special conditioning equipment is normally not considered capable of supporting high speed data for any distances in excess of 10 miles. In each of these three cases, specific actions can be taken to extend the ranges. In the cases of TROPO equipment and micro-wave equipment, a series of links can be installed to extend the circuit path indefinitely. In these cases, the number of available equipments and availability of sites become the controlling factors. In conditioning cable for distances greater than 10 miles, considerable care must be taken to ensure high quality signals can be transmitted. No specific outside limit is imposed but again the availability of conditioning devices becomes a controlling factor.

Satellites and HF are relatively little affected by distance. Perhaps the controlling factor of distance with these media is the difficulty in transmitting over them for very short distances. HF radio is known to have "dead" spots between the end of its ground wave (5-30 miles) and its first sky wave return at about 100 miles. This area, the skip zone, can be most troublesome. Its exact location will vary with frequency and many other factors. The only limitation of surface distance between the TYC-5 and the ASC utilizing a satellite path is the required separation between receiver and transmitter to avoid radio frequency interference. Simply due to the employment of satellites, this distance would be in excess of three miles.

The general interpretations on the effects of distance on medium selection would be the same at all planning levels. At the FMF and DIV levels the interpretation would be involved in system planning whereas at the CommCo level the interpretation would be involved in system implementation.

Weighting: 10, F-3, D-3, C-2

2) Availability of Material Support

This element is quite often considered late in the decision process. Since non-availability of material support, e.g., spare parts, power sources, etc., can preclude any feasible usage of a transmission system, early consideration of this element can preclude consideration of alternatives that can not be adequately supported.

This element can not be considered only once in the decision process since material support is an integral part of any system effectiveness. The availability of material support should be monitored throughout the decision process.

This element should be strongly considered at the FMF level. Some examination is also necessary at the DIV and CommCo level but in these instances it is primarily to verify the examination results done by the FMF.

Weighting: 9, F-3, D-2, C-2

3) Level of Qualified Personnel Available

This element may apply equally to any of the transmission media. If the required operator and maintenance personnel are not

available for a particular transmission medium, that medium should be avoided. If the particular system excels in all other elements, this element should then point out the need for specific actions to provide the required personnel. Typical reactions to this element may be commercial maintenance contracts.

This element should be addressed in depth at the FMF and DIV levels. The CommCo level should verify this element and make recommendations in accordance with it.

With the complexities of new equipments and the lag of the MOS classification system and T/0 reviews, a cursory review of the T/0 and on-board personnel strengths and MOSs may not be an adequate evaluation of the availability of qualified personnel.

Weighting: 9, F-3, D-3, C-2

4) <u>Power Sources Available</u>

The power sources available may dictate what transmission means can be used. Only the cable transmission medium does not have a power requirement, therefore, if only sufficient power is available for the TYC-5, cable transmission must be used. A ranking by power consumption from low to high, would normally be in this order:

1. cable
2. micro-wave
3. HF
4. TROPO
5. satellite

The power requirements and their ordering can change if specific items of equipment are compared. Planning allowance must also be made for power failures and backup power sources to allow maintenance of the normal power generating equipments. These total requirements must then be examined for availability. In some cases the total power availability may eliminate certain transmission media from consideration.

These evaluations would be first made at FMF and DIV levels. Eventually the CommCo as the operator would have to specifically address the availability of power sources.

Weighting: 9, F-3, D-3, C-2

5) Hostile Areas

In the cases where hostile areas (i. e. enemy controlled) are located between the TYC-5 and the ASC, either a circuitous route must be constructed or a method to cross over them must be used. A circuitous route by cable would then become a simple distance element evaluation. Cable through a hostile area would be of such low reliability that the effort to install it is of questionable value. In the cases of micro-wave or TROPO equipment, since both are quite directional in nature, a circuitous route would require a series of links that again would become a distance element evaluation. Additionally, the quantities of equipments required would have to be considered.

The two remaining mediums, HF and satellite can easily span large hostile areas and would be logical choices for these situations.

In evaluating this element, a variance between planning levels may exist. This would be due to the defining of a hostile area. Where the FMF level would start looking at political boundaries as a guide to the outlines of a hostile area, the DIV planner would look at localized intelligence and situation reports to define the outline of the hostile area. At the CommCo level the planner might look for safe haven islands within a "hostile area" into which a micro-wave or TROPO repeater or relay could be established, in which case, use of those equipments could be considered as a "simple" distance element evaluation.

Weighting: 8, F-2, D-2, C-2

6) Geographic Barriers

Geographic barriers such as lakes, oceans, rivers, mountains or canyons may exist between the TYC-5 and the ASC. Planning to cope with such barriers can be quite similar to the hostile area element considerations. If the laying of cable through or across the barrier is impossible or infeasible, a circuitous route is required, (if that connection is possible) and the problem becomes a distance element evaluation.

In the case of flat geographic barriers such as lakes, streams, canyons or oceans, the micro-wave and TROPO mediums are simple

distance element evaluations. If the intervening geographic barrier is raised, the micro-wave, being line-of-sight, would require at least one link to the top and one link down the other side. Here equipment and siting availability apply.

In TROPO operation a particular angle of inclination is determined by calculations involving the distance between equipments and the frequency used. If the intervening geographic barrier is flat, no problem arises. If the barrier is raised, a geometric check must be made to determine if the angle of inclination is sufficient to clear the geographic barrier.

In the case of HF, only if the geographic barrier is extremely high and close will it affect the HF transmission availability. Primarily, equipment siting will become the critical decision element.

In the case of the satellite medium, the terminals must be able to see the satellite. The actual radio transmitters in the satellites are UHF or very high frequency (VHF) both of which tend to be line-of-sight. If the transmitting or receiving satellite station is at the extreme of the satellite's earth coverage pattern, the angle of inclination would be quite small and high adjacent geographic barriers could conceivably block access from the satellite.

Although all planning echelons can evaluate the impact of the geographic barriers, the lower level planning units have a much better appreciation of the on-site geographic barriers and therefore can best

evaluate their impact on each transmission medium.

Weighting: 8, F-2, D-2, C-3

7) Transmission Speed Requirements

This element is a major element in selection of the transmission medium to be used. It is most difficult to state in a parametric manner since the alternatives addressed must be specific items of equipment.

Normally our voice channels are about 3 kilohertz (kHz) wide. High speed data will require the use of specific numbers of voice channels. Depending on the other outstanding requirements for voice or other data channels, a total number of equivalent voice channels can be established. At that point available equipments can be compared. Then those means that meet or exceed the capacity in equivalent voice channels can be compared using the other elements.

Since transmission speed requirements are usually the result of combining information requirements of higher headquarters, this element is of prime concern at the FMF level.

It should be noted that the addition of certain line conditioning equipment will enable cable to handle data rates much higher than that over normal telephone lines.

Weighting: 7, F-3, D-2, C-1

8) <u>Reliability Requirements</u>

The reliability requirements for a circuit would be directed from higher echelons. If a particular link is the only link, reliability becomes extremely important. If the particular link is the primary link for command and control or emergency type transmissions, reliability becomes of utmost importance.

Extended testing of the TYC-5 in many environments have shown it to be a most reliable terminal equipment. Therefore, any system employing it would have other factors as the determining factors in establishing reliability. This would normally be the reliability of the power sources and the reliability of the transmission medium.

The reliability of power sources is not in the scope of this paper. However, higher planning levels would have different power sources reliability factors and could assign sufficient units to ensure that power sources would not be the determining factor in evaluating reliability. Of the transmission means being evaluated, the reliability can be ranked from best to worst as:

1. Satellite
2. Micro-wave
3. Cable
4. TROPO
5. HF

Weighting: 7, F-3, D-1, C-1

9) Length of Termination Period

This element can perhaps be best divided into three segments, very short, very long and that area in between. If the circuit is only required for a short period of time, the extensive efforts of installing cable (if not already present), erecting major micro-wave towers or repositioning satellites (if necessary) are usually not warranted.

If a very long period is anticipated or involved, planning should be oriented towards relieving tactical equipments. This may then involve extensive cable plant or the use of leased commercial services or facilities.

In this context a short period of time would be less than 30 days and a long period of time would be in excess of 6 months. In the area in between these short and long periods, this element does not contribute to the decision process.

Weighting: 6, F-3, D-2, C-1

10) Availability of Frequencies

Since cable transmissions are basically free of frequency assignment problems, this element in no way degrades the use of cable. In the cases of micro-wave and TROPO, if one clear frequency within the range of the respective equipment is assigned, no problems should exist. Satellites are very similar, except cleared, compatible up and down link frequencies must be obtained to prevent difficulties.

The availability of frequencies becomes a problem when we address the HF means of transmission. Frequencies are divided between the nations of the world and are basically assets of a country for prescribed uses. Although limited policing is done to reduce unauthorized transmissions or unauthorized power levels, these problems do exist. In the case of HF medium for data transmissions, more than one frequency is required. The atmospheric conditions vary over a 24 hour period in a somewhat cyclic manner. Certain publications and even some computer applications can be used to predict the usable frequency range within HF given the distance, date and time of day. These predicted ranges will identify the maximum usable frequency (MUF), lowest usable frequency (LUF) and the frequency for optimal transmission (FOT) for a particular date over a particular range in a particular part of the world, by four or eight hour block periods. If after calculating the FOTs, four frequencies within the HF range could be picked to provide the best flexibility, you could expect continuous and sufficient HF service. The actual situation, however, is that to obtain four clear, uncluttered frequencies, one must usually start with 12 or 15 authorized frequencies. This large number will normally insure three or four good frequencies over the desired spread. The normal frequency assignments are for 3kHz bandwidth authorization. If authorization is obtained for 6kHz bandwidth frequencies, only 5 or 6 frequencies need be requested.

The importance of frequency is proportional to your relationship to using them. The CommCo would place much more importance on either obtaining 6kHz frequencies or 12 3kHz frequencies than either DIV or FMF. FMF may even go to the extreme of stating that 4 assigned 3kHz frequencies will be adequate.

Weighting: 6, F-1, D-2, C-3

11) Predicted Rainfalls

Rainfall has minimal effect on HF or satellite transmission paths. Heavy rains can have some effect on TROPO since some early refraction may occur in the heavy rain clouds. This is an extremely difficult phenomenon to predict, but should be for only relatively short periods when it does occur. A very heavy rainfall between the micro-wave sites may interfere with the signal. In high speed data transmissions, only a minimal amount of interference can disrupt an entire data string.

Perhaps the most sensitive to rainfall is the common cable system. If the cable is all buried, the rate of trouble free time during rainfalls is proportional to the quality of the installation. One small tear or opening in a buried cable will allow the water to "run" through the cable over an extensive length. This flooding can cause shorts, crosstalks or just sufficient noise to make the cable unsatisfactory for high data rate transmissions. A dry out period could take several days and might require disconnecting the cable from the communication

system and connecting it temporarily to a power system to "burn out" or "steam out" the moisture. Although these techniques work, each application of power destroys some of the insulating qualities of the cable and eventually its usefulness.

Aerial cables on poles are not as susceptible to major flooding as is buried cable. However aerial cable is much more susceptible to damage that may open the cable to the weather. Lightning, small arms fire, shell fragments or other foreign objects impacting with the cable may puncture the protective sheath and allow moisture to get at the conductors. The effect is the same as with buried cable, except the amount of water is usually much less since the funneling effect of the ground is not present.

The impact of high rainfall is mainly considered only at the CommCo level as the installer and maintainer. It would be a relatively low element in the decision process even at the CommCo level and almost no consequence at any higher planning level.

Weighting: 5, F-1, D-1, C-2

12) Predicted Snowfall

Predicted snowfalls have largely the same problems as predicted rainfalls. Only the extreme of heavy snowfalls becomes important. The moisture problem for cable is the same as for high rainfall. The interference for transmission between micro-wave towers is the same as for rainfall. The refraction difficulties in TROPO are the same as for heavy rainfall.

Certain additional problems exist when heavy snowfalls are encountered. Large amounts of heavy wet snow can cause extensive structural loading on the relatively large satellite and TROPO antennas. When in operation, sufficient heat is usually generated to cause continued melting. Some very large TROPO sets have built-in de-icing systems.

The poles supporting HF antennas and the guy lines and antennas themselves suffer from the same snow hazards as aerial cables. Sufficient amounts of snow can stick to the cables and overstress them and/or the supporting poles and a physical interruption of the signal is made. In the case of buried cable, the inacessibility for maintenance (if required) is perhaps the most striking problem caused by heavy snowfalls.

Snowfalls are not major elements in the decision making process. Greater concern about snowfalls would be made at the CommCo level since the operator would have to contend with the problems of installation and maintenance.

Weighting: 5, F-1, D-1, C-2

13) Efficiency Requirements

Efficiency, as addressed here, is the rate of new information being received compared to the rate of information being transferred; e.g., if a circuit is so bad that everything must be transmitted twice, then the efficiency for that particular circuit is 50%.

This efficiency figure is very closely tied to the transmission speed requirement. If the transmission speed required for new information is 1200 baud and one of the transmission medium being considered has only an efficiency of 50% under the prevailing conditions, a data transmission rate in excess of 2400 baud is required. Since in most systems errors increase with increased speed, a simple doubling of the speed to overcome a 50% efficiency does not completely solve the problem. The higher the data rate involved, the greater the overkill is required to compensate for low efficiencies.

Under normal conditions the five transmission means being considered would rank as follows from the best efficiency to the worst:

1. satellite
2. micro-wave
3. cable
4. TROPO
5. HF

Weighting: 5, F-3, D-3, C-1

14) Humidity Ranges

Humidity ranges are similar in consideration to temperature ranges in that common standard military specifications (MILSPECS) apply. Under these circumstances all transmission medium would be affected equally, but would generally be negligible. Extremely high humidity makes the air conditioning requirement much more stringent just as it does in extremely high temperature conditions.

A new problem arises in high humidity areas. The TYC-5 is a multi-media terminal with one media being punched cards. High humidity often causes swollen punched cards which even the most sophisticated card readers and punches have difficulty in handling. Since the TYC-5 is in a relatively small shelter (S-280, 12' X 8' X 7'), there is insufficient room for storing many punched cards for any length of time. As a result, cards are stored elsewhere and are brought in and out of the TYC-5 and other processing areas. System planning must include provisions for humidity controls on cards being transported that may eventually be used for transmission through the TYC-5.

Since electrical transmission of messages indicates some urgency, a scheduled drying period in the TYC-5 prior to transmission is unacceptable.

Weighting: 4, F-1, D-1, C-2

15) Presence of Vegetation

The types and amounts of vegetation in the area have minimal effects on HF and satellite transmissions.

In the case of TROPO, the type of vegetation the link goes over in some manner affects the reliability of the signal. Over extremely lush vegetation, TROPO usually proves to be effective for shorter distances but more apt to have signal interruptions and distortions. Over dry, sandy, hard (e. g., desert type), intervening

terrain, the TROPO signal seems to be more consistent and more apt to adequately support a high speed data link.

In the case of micro-wave, the critical consideration of vegetation presence is whether or not it masks the shot. Perfectly clear line-of-sight is required. A tree branch blowing back and forth through the path is sufficient to cause circuit disruption.

Logically, of course, sufficient clearing would be required for all transmitting facilities, be they satellite, HF (plus antennas), TROPO or micro-wave.

In the case of cable, the type and density of vegetation may dictate aerial versus burial construction due to extensive root systems. However, in some cases, the denseness of the vegetation may prohibit any type of cable construction simply due to the effort required to overcome the jungle, forest or swamps for construction.

The restrictions that the vegetation element places on the use of cable would probably be noted at all levels of planning. The vegetation element limitations on microwave and TROPO would probably only be addressed at the lowest level since an actual installation may be required to determine whether or not the vegetation in a particular situation is derogatory.

Weighting: 4, F-1, D-1, C-2

16) <u>Predicted Winds</u>

High winds within the area can create problems. They are relatively easy to identify. The TROPO and satellite antennas are

most vulnerable to problems of wind loading. When specific equipment is being compared, the wind loading specifications on each equipment can be compared.

An additional problem may arise in micro-wave links due to high winds. Since micro-wave is very critically line-of-sight, cross winds may set up vibrations of the micro-wave antennas. If the vibrations exceed a rather small amount, circuit interruption may well occur. Such a deficiency may be compensated for by sturdier installation techniques.

Problems caused by winds would be of greater importance to the operating agency, the CommCo and of much lesser importance to the DIV and FMF.

Weighting: 3, F-1, D-1, C-2

17) <u>Termination with a Naval Communications Station</u>

In examining this element we should concede that cable or micro-wave terminations are not done with a NAVCOMMSTA since the signal path would be one that is readily acceptable to an ASC and not require any further conversion. Normally a TROPO link would fall into this same category since it is usually just a link within basically a cable or micro-wave system.

This leaves HF and satellite. In the case of satellite transmissions, present technology and procedures require both stations on a link to be able to view the same satellite at the same time. This

alone will determine if a satellite link is feasible. The next step would be to determine which NAVCOMMSTAs within the satellite's coverage area are equipped to terminate the particular type of satellite transmission. The final step would be actual contact with the NAV-COMMSTA to ensure that the station was able to accommodate an additional satellite termination and process it through the NAVCOMM-STA to an ASC.

All NAVCOMMSTAs are not identically equipped, therefore in the case of HF termination, a query to the NAVCOMMSTA designated as the Communications Area Master Station (CAMS) would be required. The CAMS would identify and assign the proper NAVCOMMSTA to terminate with.

Weighting: 3, F-3, D-2, C-1

18) Sites Available

The sites available in most cases are completely adequate for any of the transmission systems. Only the extreme conditions would cause problems. A very small site may restrict certain types of long wire HF antennas, a very small site may preclude installation of space diversity TROPO antennas, or not provide sufficient space for guy lines for a tall micro-wave tower if one is required to get over adjacent geographic barriers or surrounding vegetation.

Very large sites may include such geographic variances that the antennae are ideally sited at a point so far from the ideal site of the TYC-5, that another transmission system is required between them.

Only if the very small site is obvious (e.g. a very small mountain peak) will this element be considered at FMF level. This element is considered at DIV and mainly at CommCo level.

Weighting: 2, F-1, D-2, C-3

19) <u>Temperature Ranges</u>

Temperature ranges for all of the transmission medium being considered have minimal impact. The electronic design of the equipments are built to MILSPECS which normally far exceed the temperature ranges to be encountered. There is however collateral problems if temperature variations occur. Perhaps the heat is the most pressing problem. The equipments are designed in most cases with sufficient cooling capacity or else a component air conditioner is provided. If all equipment is working properly there is no problem. However, a partial power failure which may disable the air conditioner, yet not a transmitter, could cause the system to be shut down. This holds true for all configurations since the TYC-5 itself would also be affected.

One other possible extreme would be extreme cold. In this case the frozen earth would be a major obstacle in any construction or tower/antenna erection. In this case a cable system would be at a decided disadvantage since extensive construction efforts would be required.

Since the extremes are not usually the case, only "warmer than usual" temperatures would bring any concerns. At the FMF

level, perhaps additional provisioning of power units would be considered. At the DIV and CommCo levels the availability of generator mechanics and refrigeration mechanics would be of concern.

Weighting: 2, F-2, D-2, C-2

20) Predicted Freezing/Sleet

In areas with frequent freezes or sleet, the elements of heavy rainfall and heavy snowfall are even further complicated. In the cases of sleet, the additional problem factor would be that denser amounts of material would be clinging to any structures.

The freezing problems would be the same considerations as mentioned under very low temperature conditions. (see element 19).

This element does not stand alone but instead combines the heavy precipitation (snow and rain) and the temperature (lower extreme) elements. Therefore this element alone would not be the basis for decision.

Weighting: 1, F-1, D-1, C-2

LIST OF REFERENCES

1. Naval Electronics Laboratory Center Technical Note 2128, <u>Remote AUTODIN Operation Over HF, Troposcatter, and Satellite Links</u>, by G. A. Clapp and R. L. Hollandsworth, 14 September 1972.

2. 1st Marine Aircraft Wing Letter 6:LEB:wpc over 2000 to Marine Corps Development and Education Command, Subject: <u>Task Force Delta Communications, the Rosegarden Experience</u>, 8 March 1973.

3. 9th Communications Battalion Letter BED/mgs over 2300 to Commandant of the Marine Corps, Subject: <u>Data Communication Terminal AN/TYC-5(V) and Tactical Satellite Communications Terminal AN/TSC-80 Compatibility Testing</u>, 9 June 1971.

4. Naval Electronics Laboratory Center Technical Note 2295, <u>AUTODIN Operation on Tactical HF and Troposcatter Radio Links</u>, by G. A. Clapp and J. L. Heritage, 23 February 1973.

5. Naval Electronics Laboratory Center Technical Note 2463, <u>AUTODIN Data Efficiency on a 6200 Mile HF Circuit</u>, by G. A. Clapp, 21 August 1973.

6. Farber, D. J., "Networks: An Introduction," <u>Datamation</u>, p. 36-39, April 1972.

7. Kleinrock, L., <u>Analytic and Simulation Methods in Computer Network Design</u>, paper presented at AFIPS Spring Joint Computer Conference, May 1970.

8. Roberts, L. G. and Wessler, B. D., <u>Computer Network Development to Achieve Resource Sharing</u>, paper presented at AFIPS Spring Joint Computer Conference, May 1970.

BIBLIOGRAPHY

1. Naval Electronics Laboratory Center Technical Note 2128, Remote AUTODIN Operation Over HF, Troposcatter, and Satellite Links, by G. A. Clapp and R. L. Hollandsworth, 14 September 1972.

2. Naval Electronics Laboratory Center Technical Note 2295, AUTODIN Operation on Tactical HF and Troposcatter Radio Links, by G. A. Clapp and J. L. Heritage, 23 February 1973.

3. Naval Electronics Laboratory Center Technical Note 2463, AUTODIN Data Efficiency on a 6200 Mile HF Circuit, by G. A. Clapp, 21 August 1972.

4. Farber, D. J., "Networks: An Introduction," Datamation, p. 36-39, April 1972.

5. Frank, H., Frisch, I. T. and Chou, W., Topological Considerations in the Design of the ARPA Computer Network, paper presented at AFIPS Spring Joint Computer Conference, May 1970.

6. Heart, F. E. and others, The Interface Message Processor for the ARPA Computer Network, paper presented at AFIPS Spring Joint Computer Conference, May 1970.

7. Kleinrock, L., Analytic and Simulation Methods in Computer Network Design, paper presented at AFIPS Spring Joint Computer Conference, May 1970.

8. Roberts, L. G. and Wessler, B. D., Computer Network Development to Achieve Resource Sharing, paper presented at AFIPS Spring Joint Computer Conference, May 1970.

9. Terry, R. D. and Rainwater, W. M., "DOD Leased Communications and the New Competition," Signal, p. 6-7, January 1974.

10. 1st Marine Aircraft Wing Letter 6:LEB:wpc over 2000 to Marine Corps Development and Education Command, Subject: Task Force Delta Communications, the Rosegarden Experience, 8 March 1973.

11. 9th Communications Battalion Letter BED/mgs over 2300 to Commandant of the Marine Corps, Subject: Data Communication Terminal AN/TYC-5(V) and Tactical Satellite Communications Terminal AN/TSC-80 Compatibility Testing, 9 June 1971.

12. Deputy Secretary of Defense Memorandum, Subject: Policy for AUTODIN, AUTOVON and AUTOSEVOCOM Service, 5 March 1973.

13. SECNAVINST 11120.1D, Subject: Programming of Major Telecommunications Requirements, 19 November 1968.

14. OPNAVINST 11120.5, Subject: Communication Requirements; policy concerning, 9 March 1967.

15. OPNAVINST 5450.184A, Subject: Commander, Naval Telecommunications Command; mission and functions of, 16 October 1973.

16. ACNO(COMM)INST 2300.1, Subject: Assignment of Priorities to Communication Improvement Objectives and Communication Requirements, 11 March 1969.

17. Defense Communications Agency Circular 310-130-1, Subject: Submission of Telecommunications Service Requests, March 1970.

18. Defense Communications Agency publication, Subject: Satellite Communications Reference Data Handbook, July 1972.

19. USASTRATCOM SCCC-TED-73-TP-86, Subject: Operational Comparison Test and Evaluation of High Frequency (HF) ModemsTest Plan, August 1973.

20. COMNAVTELCOMM message 121457Z Sep 73, Subject: Telecommunications Resources FY 74-80.

LIST OF ACRONYMS AND ABBREVIATIONS

ACK	Acknowledgement
ARPA	Advanced Research Projects Agency
ARQ	Automatic Request for Retransmission
ASC	Automatic Switching Center
ATCU	Air Transportable Communication Unit
AUTODIN	Automatic Digital Network
AUTOSEVOCOM	Automatic Secure Voice Network
AUTOVON	Automatic Voice Network
BER	Bit Error Rate
CDC	Control Data Corporation
CommCo	Communications Company
CRT	Cathode Ray Tube
DCA	Defense Communications Agency
DCASEF	Defense Communications Agency System Engineering Facility
DCS	Defense Communications System
DCSCS	Defense Communications System Contingency Station
DEPSECDEF	Deputy Secretary of Defense
DIV	Division
DOD	Department of Defense
DSTE	Digital Subscriber Terminal Equipment

DTAS	Digital Transmission and Switching System
EDAC	Error Detection and Correction
FMF	Fleet Marine Force
FOT	Frequency for Optimum Transmission
GMT	Greenwich Meridian Time
HF	High Frequency
HQMC	Headquarters, U. S. Marine Corps
IMPS	Interface Message Processors
I/O	Input/Output
JUMPS	Joint Unified Military Pay System
LDMX	Local Digital Message Exchange
LES-6	Lincoln Experimental Satellite-6
LOS	Line of Sight
LUF	Lowest Usable Frequency
MAXSAFE	Maximum Throughput Store and Forward EDAC System
MHF	Message Header Formatter
MILSPEC	Military Specification
MILSTD	Military Standard
MIS	Management Information System
MMS	Manpower Management System
MTDS	Marine Tactical Data System
MUF	Maximum Usable Frequency
MVL	Majority Vote Logic

NACK	Non-Acknowledgement
NAVCOMMSTA	Naval Communications Station
NAVTELCOM	Naval Telecommunications Command
NELC	Naval Electronics Laboratory Center
OCR	Optical Character Recognition
RF	Radio Frequency
RI	Routing Indicator
S/N	Signal/Noise
TACSAT-1	Tactical Satellite-1
TADIL-A	Tactical Data Link-A
TROPO	Tropospheric Scatter
TTY	Teletype
USMC	United States Marine Corps
VFCT	Voice Frequency Carrier Terminal

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MTACCS Test Division, MCTSSA
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1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Using the Mobile Data Communications Terminal AN/TYC-5 as an AUTODIN Terminal		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis March 1974
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Bruce David Thoreson		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Postgraduate School Monterey, California 93940		12. REPORT DATE March 1974
		13. NUMBER OF PAGES 132
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Tactical AUTODIN
High Speed Data Transmission
Mobile Data Terminal
AN/TYC-5

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This thesis examines the use of the TYC-5 as an AUTODIN terminal, working from a remote location into AUTODIN. Emphasis is placed on examining the various transmission mediums used to support the TYC-5. Included are cabl micro-wave, tropospheric scatter, high frequency radio and satellite. Required accessories; operational experiences, expected reliabilities and efficiencies; and operational parameters/constraints are examined for each medium. The shortfalls that exist today in providing each of the mediums arc

20.

identified. The responsibilities for providing support to eliminate these shortfalls are also identified. The conclusions show the preferred TYC-5/ transmission medium combination to be with cable/micro-wave. The most critical shortfalls are also identified. The twelve recommendations are actions that should be taken to reduce shortfalls and provide for better high data rate communications from a remote area.

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